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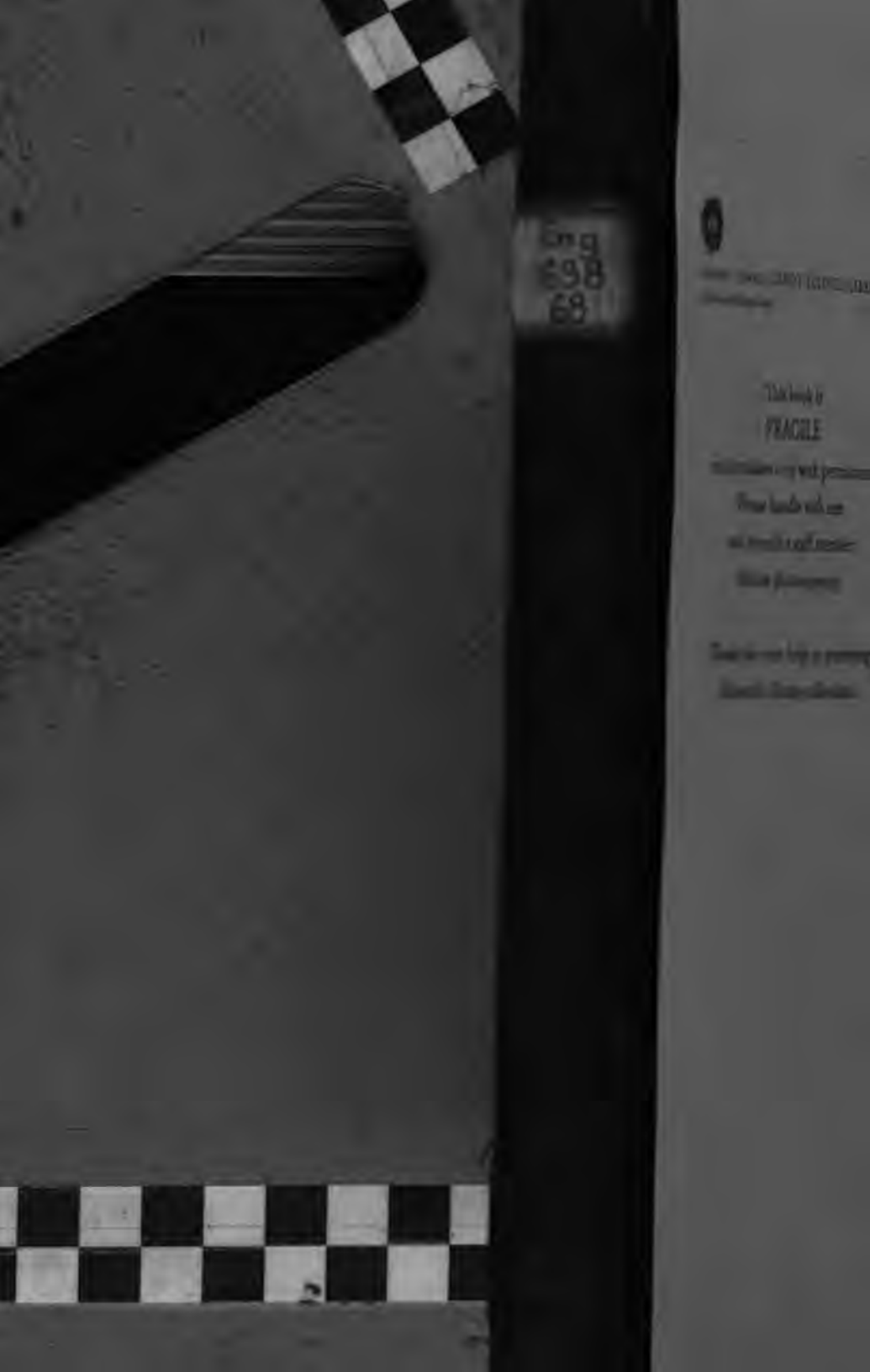

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THE

MECHANIC'S AND STUDENT'S GUIDE

IN THE

DESIGNING AND CONSTRUCTION

OF

GENERAL MACHINE GEARING,

AS

ECCENTRICS, SCREWS, TOOTHED WHEELS, ETC.,

AND THE DRAWING OF

RECTILINEAL AND CURVED SURFACES;

WITH

PRACTICAL RULES AND DETAILS.

EDITED BY

FRANCIS HERBERT JOYNSON,

AUTHOR OF "THE METALS USED IN CONSTRUCTION."

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THE

MECHANIC'S AND STUDENT'S GUIDE.

CHAPTER I.

OF THE ECCENTRIC CURVES.

PLATE I.*

(1.) ECCENTRIC curves are those curves in whose surface there is not a point which is of equal distance from the centre. The main object of these curves is to produce an alternate backward and forward sliding motion, either vertical or horizontal, just as it is required for machinery, as, for instance, for slide valves, pumps, presses, etc.

It may be remarked that elipses belong as well to these curves, even the common eccentric of an engine, if in the latter the centre is not taken into consideration. The first problem we have before us is "a double eccentrical and symmetrical curve" (Fig. 1), which, by being connected by part of the circles B D E H, and A G F D, produce a stationary position on the point D, whilst the centre, C, turns round. It will be observed

* The reader is supposed to be acquainted with the elements of Mechanical Drawing, so as to be able to lay down and copy drawings. He will find in the last chapter a selection of problems in geometry, the most directly applicable to the purposes of the mechanic.

that the circle A G F D^1, is divided in four parts, and that, when E has turned to D, point F will be at I. Point F will now begin to rise, till it has gone through the quadrant I D^1. Here the stationary position, or the point of rest, will commence, as D has now been moved to D^1, where it will remain till the next quarter-circle, D^1 K L, has been run through. By this time A has arrived at D^1, and this point, D^1, will gradually return now to D, while the curve has gone through the next quadrant, leaving still one-eighth of a circle for D to get to its original position.

(2.) To construct this curve, the inner circle, B D E H, and the outer circle, A G F D^1, has to be determined on by the length of travel from D to D^1. This having been done, divide the circle into four parts, also divide the quadrants into any number of equal parts, say six, and draw radial lines to the centre C. As we have taken six divisions, we have also to take six divisions between the outer and the inner circle, from which semicircles are struck and points of intersection found, as shown in drawing, which points have only to be connected, and the eccentrical and symmetrical curves in each quadrant are found.

(3.) Fig. 2. *To Construct a Double Eccentrical and Symmetrical Curve.*—In the present example the point D is moved with a variable speed from D to D^1, the speed of its rising increasing in regular proportion from the beginning of the curve to the vertex, E, and decreasing in the same proportion, for the point D^1 to return to its original position, D.

(4.) After having determined on the size of curve by circle D^1 F E G, and the throw or stroke of D to D^1, describe the half-circle, D D^1, divide the circumference into any number of equal parts, say 10, and draw perpendiculars to the centre line, D^1 C E. The points

a, b, c, d, e, f, g, h, i having been found, draw semicircles from centre C through the latter, then proceed in dividing the large circle, D^1 F E G, in double the number of parts than the half-circle D D^1, mentioned above; draw radial lines, C^1 C^2 C^3, etc., and connect the intersections of the various semicircles and radial lines, beginning at semicircle *a* and radial line C^1, semicircle *b* and radial line C^2, and so forth, and the curve required is found.

(5.) The motion of this curve is symmetrically slower and quicker, because the distance, D D^1, is divided into unequal parts, increasing symmetrically from the respective points.

(6.) Fig. 3. *To Construct a "Heart" Motion.*—Before proceeding with the construction of this kind of curve, it may be observed that it is also a double eccentrical and symmetrical curve, producing a uniform and a straight motion, of which the length or stroke would be from D to D^1, and in imagining C as the centre of the shaft, the point D would have to traverse to D^1 in each half revolution.

(7.) After the stroke has been determined, draw inner and outer circles, here A D, and D^1 F E G; divide the same into any number of parts, say 24, and draw radial lines, 1, 2, 3, 4, etc.; proceed in dividing D to D^1 in half the number of parts to those on the circumference, here 12, and draw semicircles through them, and at intersections of radial lines, 1, 2, 3, 4, etc., will be the different points for the curve of the heart motion.

(8.) Fig. 4. *To Construct a Double Eccentrical Curve which is not Symmetrical.*—In noticing this diagram, it will be seen that the point D will move equally through the arc D D^1, which is part of a circle, struck from a

point C, of the circle A B C. After dividing this arc into any number of parts, say 6, intersect these points, 1, 2, 3, etc., by semicircles; then divide the circle, A B C, into double the number of parts, here 12, and divide the circumference, beginning at C. This done, take the radius, C D, and begin to mark off from 1^1 to F, from 2^1 to G, from 3^1 to H, and so on, till all points are served alike; connect these points, and the curve is found, which will move point D to D^1 equal through the arc described from C, assuming the motion equal through the axis E. The reason of this is because the circle A B C, being divided into equal parts, divides all the semicircles into equal parts as well, therefore all angles will be alike, as will be seen on diagram. Imagining E F to move to 1, G will move forward to the same position of radial line as E F was, or, in other words, forming the same angle as E F, and so forth, with every point of the curve, till each of them has passed through the arc, D D^1.

(9.) It will also be seen that each half of this disc is not symmetrical to each other, because E D^1 does not go vertical through the centre E; however, the motion of this half part of the curve is just as equal through the arc D D^1 as on the other side, because the circle, the semicircles, and the arc D D^1 are equally divided, and as all the set-offs from the circumference of circle A B C have been equal. The reciprocating action of this disc is equal throughout, though the disc is not symmetrical, because each equal angle passes in equal times through equal spaces, assuming, as aforesaid, equal motion through the axis. A greater speed is obtained on the different points of the circumference, yet only these are affected. The travel of D to D^1 and back again will be done in the same time as the other.

(10.) Fig. 5. *The Evolution of a Circle.*—In Engineer-

ing, this kind of curve is frequently made use of; for instance, for cams of hammers, for setting out racks and pinions, to obtain the proper shape of the tooth, etc. The segment of a circle, whose length is wound off into a straight line, will form an evolution of a circle. Geometrically this line is found thus: the circle having been determined on, divide the segment into any number of parts, say 12, the shorter the better, on account of the curve of the circle; draw radial lines to the centre C from these points 1, 2, 3, etc., and at right angles draw tangents, then put on No. 1 tangent the distance from A to 1; on No. 2 tangent double the distance from A to 1, as 2 *a*; on No. 3 tangent, three times the distance from A to 1, 36, and so on till all the points are gone through; and the evolution of the circle is found by drawing the curve through the points *a b*, etc., to D.

(11.) Fig. 6. *Spiral Lines.*—A spiral line is described by supposing a fixed point, and another point moving round the same continually. If the moving point has gone once round the fixed point, the spiral is said to have one revolution, and so forth, according to the number of laps round the fixed point. The fixed point is called the centre of the spiral. There are several modes of setting out the same. Fig. 6 is done thus, and has this peculiarity, that the distance at the first revolution from *a* to *b* is equal to the distance *b* to *c*, and so on by continuing the diameter of the spiral. The curve of this kind of spiral is formed by a continuation of circles, whose centres lie in the different tangential points, which will easily be seen by a glance at the Drawing. In a succeeding chapter, a few examples of curves, useful in mechanics, will be described.

CHAPTER II.

OF THE SCREW.

PLATE II., FIGS. 1, 2, 3, 4, 5, 6.

(12.) A POINT, which rises in equal distances and proportion round the surface of a cylinder, will describe the curved line of a screw. To show the latter more distinct, the elevation (Fig. 1), and the Plan (Fig. 2), of the cylinder are drawn in dotted lines, and the curve which the point A describes, in full lines. To draw the elevation, we must assume a height and a diameter of a cylinder for the point A (Fig 1), to be once round the surface of the same, shown in plan (Fig 2), by A B C D. After fixing therefore the centre line, L L, divide the assumed height of cylinder, from A to A^2, into any number of equal parts, say 16, and draw them parallel to the base line A B C; the same is done to the periphery of the circle in plan (Fig 2), which will be divided into any number of equal parts,—of course here as above, into 16 parts,—which will show the different positions which the point A will assume, whilst it moves round the surface of the cylinder, A B C D. Draw vertical lines from the different divisions, *a*, *b*, *c*, *d*, *e*, *f*, etc., (Fig. 2), to the different horizontal lines in Fig 2, as from *a* to *a*, from *b* to b^2, and so on, and connect the intersections. The curved line of a screw is found by drawing a curved line, a^1, b^1, c^1, through these points. Of course the lower the height, the flatter or slower the curve.

(13.) The screw is a cord wound spirally round the periphery of a cylinder, and is therefore an inclined

plane, the length being the circumference of the cylinder, and the height, the distance between two consecutive cords or threads of the screw. The greater the diameter of the screw, the greater will be the length of the plane to its height, which runs in a continued line round the centre of the cylinder. There are different forms of threads, either V threaded, round or square, as well as screws with single and several windings,—of course their nuts corresponding exactly to the diameter and shape of the thread of the screw. After this definition we shall proceed in setting out a screw with a V thread, shown in elevation (Fig. 3), and mode of setting out the curve in plan (Fig. 4).

(14.) The outside diameter of the screw having been decided, in the present instance 3 inches, draw centre line, L L, for plan and elevation, showing the former only by half a circle, as it will suffice, the different points for division lying directly opposite. Fix on the number of threads in one inch, according to standard tables, or as in Fig. 3, $\frac{3}{4}$-inch pitch, the centres from thread to thread; divide this height, F^1 C G, into, say 16 parts, treating plan (Fig. 4) in the same way; draw verticals from a to a^1, b to b^1, etc., as in Figs. 1. and 2, to find points of intersections for the curved line. The inside diameter of the screw will be found by the angle of the thread, the best angle being 55°. The points D E having been so found, represented in plan (Fig. 4), by half a circle, D F E, which will be divided in the same number of parts by radial lines as outside diameter of screw; draw perpendiculars from g to g^1, and h to h^1, to division lines in elevation,—the points of intersection for the inside curve are found, through which the curve line is drawn by hand.

(15.) If once the curves have been arrived at, the draughtsman will facilitate his work by cutting out of card-board or wood, a template, which will suit the

remaining curves, and showing by dotted lines the rising of the thread not in view. (*Note.*—In practice the point and the bottom of thread is rounded off.)

(16.) We shall continue now in setting out a square and treble-threaded screw, which kind is generally used to receive a quick action, as in presses and other machines. The principle of finding the curved lines is sufficiently explained in preceding Figs. 1, 2, 3, and 4, and the scholar will have to fix on the diameter and the pitch. In the present example, the outside diameter of the screw is 3 inches, and the pitch of the thread ½-inch, the depth of the same equal to half the pitch shown in plan (Fig. 6), by a half-circle, D E F, 2½ inches diameter. After setting out the thread in elevation (Fig. 5), arrange the plan and find the outside curve, and proceed with the inside one in the same manner. It is to be remarked that part of the inside curve will be out of sight, shown in dotted lines, as the winding round covers the same.

(17.) Fig. 7 shows the elevation of a bolt, ⅝ of an inch in diameter, with nut and washer; Fig. 8, plan of nut and washer; Fig. 9, plan of head. The necessary dimensions for a bolt in practice, are the diameter and the length between head and washer, as shown in Fig. 7 by 3 inches. They are different tables for sizes of head and nut; however, the draughtsman will find the following rule very useful, to which the present bolt in Fig. 7 is drawn: "The height of the nut to be equal to the diameter of the bolt; the width over the flat sides of the hexagon to be equal to as many fifths of inches as there are eighths in the diameter of the bolt; the square of the head to be to this very proportion; the height of the latter to be half of the width over the flat sides of the hexagon." In drawing small sizes of bolts, the curved line will only be shown by straight or slightly slanting parallel lines, to show how far down a bolt has to be screwed or chased.

CHAPTER III.

OF THE CONSTRUCTION OF TOOTHED WHEELS.

(18.) THE proper formation of the teeth of wheels is an object of the greatest importance in constructing machinery. Uniformity of pressure and velocity will be ensured by an equal action of the teeth upon each other, and if such is not the case the wheels will work badly, jump, and perhaps break—thus good working all depends on the setting out the same in the most advantageous manner.

(19.) For wheelwork and machinery in general, the term of "gearing" is employed; however, two tooth wheels are also said to be "in gear" when they have their teeth engaged together, and likewise to be "out of gear" when they are separated and not in action.

(20.) Tooth wheels are the most important organs in mechanism for transferring motion from one shaft to another, either parallel or at any angle, as in the case of (*a*) "spur gear" and (*b*) "bevel gear." In the former case (*a*) it may be mentioned that their action may be regarded as that of two cylinders, and in the latter (*b*) as that of two cones rolling upon one another.

(21.) When two toothed wheels act upon each other, the greater is called the "wheel," and the lesser the "pinion." If the teeth of the wheel or pinion are of one and the same piece as the body, they are called "teeth;" and if they are of a separate material, they are called "cogs." The latter are made of well-seasoned hard wood, such as beech, fixed in the mortises provided in the rim of

the cast-iron wheel, and the tenon of each tooth is secured by a wrought-iron pin. These wheels are also called "mortise-wheels," and are very much preferred where a great speed is required, on account of their smoothness in working, geared with cast-iron wheels, and causing only little vibration.

(22.) The straight line drawn from centre to centre of a pair of wheels, is called the "line of centres," as c^1 c^1, Fig. 1. Plate VI. The "pitch line," by which the size of a wheel is always given, represents, as noted above, the touching of two cylinders rolling upon one another, and on whose periphery the number of teeth are set out, as the dotted circles E and G in Fig. 1. Plate VI.

(23.) Plate III., Figs. 1, 2, 3, 4. *The Elevation and Plan of a Pinion, and also the same set at an Angle.*— To draw a skew view of a pinion, as Figs. 3 and 4, it is firstly required to make a regular side elevation and plan of the same (Figs. 1 and 2), and then to copy the plan on to any given angle, and produce the same by such plan, Fig. 4, and by the side elevation, Fig. 1. The pinion illustrated is $4\frac{3}{4}$ inches diameter × 15 teeth × 1″ pitch × $2\frac{3}{4}$ inches wide.

(24.) After the centre lines and the pitch line have been drawn, and the teeth set out, which are shown here by striking the curves from the centres of the spaces, and the teeth by regular circles, carry each tooth down on to the breadth of the pinion (plan, Fig. 2). The pitch line is shown by the dotted line, *a b c d*, the face of the wheel by A B (Fig. 1), in elevation, which, of course, will only show straight lines by looking on the top of the pinion by A B (Fig. 1), and A^1 B^1 (Fig. 2), in plan, to which lines every tooth, as aforesaid, is carried down, A A^1 and B B^1 showing the breadth. The proportion of the depth of the tooth is equal to the pitch multiplied by ·75, and from the pitch

line to the top of the tooth, equal to the pitch multiplied by ·33.

(25.) After the plan has been copied on any given angle (Fig. 4), the pitch line will have to be found first, the vertical height being the same as on Fig. 1, and equal to *b d;* the breadth *a* to *b*, however, will have to be carried first down to the plan, Fig. 2, copied on to Fig. 4, and then carried on the centre line, X X; in fact, any point carried over from the pitch line to the different views of the pinion will find the ellipse required for showing the elevation of the pinion askew. On the pitch line, which being so found, add the height of the tooth above and below pitch line from elevation (Fig. 1), which lines will have to be struck concentric with the ellipse, therefore out of its centres; then carry each point of the tooth on to these said lines from the elevation (Fig. 1) and plan (Fig. 4), and the shape of each tooth is found by connecting these points by curves, or by regular circles, which will meet in these points. This is illustrated by the tooth marked C; 1 and 2 in elevation is carried across horizontally to the line found for the top of the tooth, 3 and 4 to the elliptical pitch line, and 5 and 6 to the line for the bottom of the tooth, which points also correspond by drawing the different points from the plan (Fig. 4). After all the teeth are so set out on the elliptical pitch line, begin to draw the breadth, A A^1, of the pinion, which will necessarily show, as the pinion is standing askew. Point A^1 will lie in the centre line, X X in A^1, and the different points are found the same, as explained above, and shown in dotted lines.

(26.) Plate IV., Fig. 1. *The Rack and Pinion.*—For the construction of the above we have taken a pinion $5\frac{7}{8}$ inches diameter, with 9 teeth and 2 inches pitch × $3\frac{1}{2}$ inches wide, drawn to a scale of $\frac{3}{8}$ of an inch,

equal to 1 foot. After having set out the pitch line, B D E F, divide the same into the number of teeth required, and find the shape of the tooth by the evolution of the circle on the tangent A B C. The dotted lines show the mode for finding the curved line, which will be found sufficiently explained in Plate I, Fig. 5, par. 10. The size and shape of the tooth having been so found, the teeth of the rack will have to be carefully set out, leaving sufficient clearance on the top and bottom of tooth, so that the teeth do not the least touch the bottom of the rack or pinion. The height of the tooth on the rack will of course depend on the height of the tooth of the pinion. It is to be remarked, however, that each tooth of the rack is part of a cycloid, which, after having been found, may be easily struck with a compass, as it will vary but little with that of a circle, the curve being so very short.

(27.) Plate IV., Fig. 2. *The Internal Spur-wheel and Pinion.*—The wheel and pinion in question are drawn to the last-named scale, the diameter of the wheel being 3 feet $9\frac{7}{8}$ inches × 72 teeth × 2 inches pitch × 4 inches wide, cast in segments, which are not shown here, because it is only intended to illustrate the setting out of the teeth, and therefore the wheel shown broken off. The diameter of the pinion is $7\frac{5}{8}$ inches × 12 teeth × 2 inches pitch × 4 inches wide.

(28.) Hence follows that, after having set out the pitch lines, the circle B G is rolling inside the circle A B C, and describing the curve (*see* explanation of Plate I., Fig. 5, par. 10), and shown as well here by dotted lines, to get the curve for the tooth of the wheel. In the present example we are assuming that the wheel is moving the pinion, and the curve described will be a part of the epicycloid, generated

by a point of the circle, A B C, which is moving round B D E F, and therefore the curve for the tooth of the pinion. The plan is left away here as well as for preceding Fig. 1, as the beginner ought readily to draw the same if he knows the breadth.

(29.) Plate IV., Figs. 3 and 4. *The Worm and the Worm-wheel.*—By glancing at the elevation of Fig. 1, it is at once perceived that the form of the thread of the screw and the teeth of the wheel is on the same principle as that shown and explained in Fig. 1 of this plate; the only difference is, that instead of a straight tooth like that of a rack, it is a screw, the shape and curve of the thread forming the tooth, constructed by a cycloid, and that of the wheel by the evolution of a circle on the straight line, which is not shown, to accustom the beginner in applying himself to those rules already given.

(30.) The drawing is to a scale of 3 inches, equal to 1 foot, or $\frac{1}{4}$-inch scale. The dimensions are thus: The diameter of the worm on the pitch line, *a b*, 4 inches; the diameter of the wheel, $16\frac{9}{16}$ inches × 26 teeth × 2 inches pitch × 3 inches wide.

(31.) The pitch line for the worm-wheel will in this case lie in the centre line, A^1 B^1, of the wheel and worm (Fig. 4), as will be seen by the plan. In elevation, the teeth are shown dotted on the pitch line. The reason of this will be perceived by referring to the plan, as the points *c* and *d* are above the height of the teeth at the centre line, A B, the form of the tooth being a semicircle to the pitch line, *a b*, of the worm. Sufficient clearance at top and bottom of teeth must also be provided. The skew of the tooth will depend wholly on the inclination of the thread of the worm; and this skew must be transferred from the elevation to the plan, where the full face of a tooth is seen; here, for

instance, the tooth *e*, the breadth of which being at the pitch line, corresponding to the one found by setting the tooth out at the proper instant. The tooth, as seen in plan, is rounded to the outside, so that one tooth works freely into the other. The teeth are also bevelled, to prevent too much friction and unnecessary length, for the wheel to work at the centre of tooth, and that if one tooth has worked through, the next one is totally at work.

(32.) To show in the plan the different views of the teeth, tooth *e* must be drawn first on the face line, *c d*, and the circumference, *c d* and *e f*, found by the bevelling, brought up to the elevation, the radius of the new pitch line lying at *g*. The outside of the teeth being now set out, and also the skew drawn up from tooth *e* in plan, and every tooth in the elevation dealt with the same as tooth *e* in elevation, vertical lines from the elevation down to the plan of each tooth will then give the different forms of each tooth in the plan.

(33.) The screw is sufficiently explained on Plate II. However, it must be remarked that, in cases of connection of the worm and the wheel, the former is always the driving motion.

(34.) Plate V., Figs. 1, 2, 3, 4. *The Elevation and Sections of a Spur-wheel with Four Arms.* — Size of wheel, 1 foot 2¾ inches × 46 teeth × 1" pitch × 2½" wide. After the pitch line and all the required centre lines have been drawn, the teeth are set out in the same manner as before described. Produce the same on the section and end elevation (Figs. 2 and 3) by deciding on the breadth required (here 2½ inches). The size of tooth on Fig. 3 is shown by the crossed lines, *a b* and *c d*. This being done, draw the thickness of the rim, ⅝ inches, shown in elevation by circle, A B C D; draw size of boss, E F G H, and hole through the same in elevation,

and producing it in section by determining a required length (here $3\frac{1}{2}$ inches).

(35.) The four arms are the next to be set out, tapering from the boss to the rim, Fig. 1, whose section is shown in Fig. 4, and taken at X X. The extra projection or thickness at the centre of the rim at I (Fig. 3) is to give the rim additional strength to overcome the strain on the teeth; in Fig. 1 this projection shows a circle, I I. The centre plate, K, of the arms enters into the latter, whilst the rib, L, runs from the body of the boss to the rim of the wheel. The teeth in the end elevation are found by drawing each tooth separately from the side elevation, Fig. 1, on to the breadth of the wheel, Fig. 2, which dotted lines sufficiently denote.

(36.) Plate VI., Figs. 1, 2, 3, 4, 5. *The Spur-wheel and Pinion.*—After the preceding explanations of the construction of teeth for wheels, it is an easy matter to draw any spur-wheel or pinion. The drawing of the elevation of a spur-wheel and pinion is represented in Fig. 1; the diameter of the wheel being 6 to 1 to that of the pinion, of course the diameter, as in all toothed wheels, measured at the pitch line, shown by the dotted lines in both wheel and pinion. The main dimensions of the present wheels are thus: Diameter of wheel, 3 feet × 72 teeth × $1\frac{1}{2}$″ pitch × 3 inches wide; diameter of pinion $5\frac{3}{4}$ inches × 12 teeth × $1\frac{1}{2}$ pitch × $3\frac{1}{2}$ inches wide, and are drawn to a scale of 2 inches equal to 1 foot. Fig. 2. The section of the wheel through *a b*, *c d*, *e f*, are for the purpose of showing the strength of the boss, the arms, the rim, as well as the breadth and size of the tooth; the latter, to show more distinctly, and as done in practice on full-sized drawings, crossed by diagonal lines. Fig. 3. The end elevation of both wheel and pinion. Fig. 4. A

section of the pinion, to show pitch plate A B, as in cases for crabs, lathes, and other machinery, to prevent the wheel from running off. Fig. 5. A section through the arm at *g h*, Fig. 1. After having determined the size of both wheels required in the present drawing, as above, the centres are found by halving the diameters of each, and adding them together, which would give 1 foot $8\frac{7}{8}$ inches; draw, then, the pitch lines, and divide the same in the number of teeth required by the pitch given. Now we shall presume that the pinion is driving the wheel, therefore the shape of the former must be that of an epicycloid, which is formed by a point having C E as diameter of circle C D E F, rolling along the pitch line E G H. The curves in small-scaled drawings are, however, quite accurately enough drawn by regular arcs from the centre of the tooth.

(37.) Plate VII., Figs. 1, 2, 3, 4. *Of the Bevel Wheel.*—The action of wheels whose axes are angular to each other, are called bevel wheels. The principle, we may observe again, is depending on the frustra of two cones being brought into contact with each other.

(38.) In order to illustrate this, these cones are drawn by dotted lines on Figs. 1, 2, 3, 4; C being their respective apex or centre, all the four figures showing the sections of bevelled gear at different angles through the centre of the wheel; the size of the tooth being marked by a cross is the regular mode in practice, to show clearly the pitch line, as well as the depth of the tooth.

(39.) The breadth of the tooth may be made to any dimension, according to the strength required, and to be enabled to overcome greater resistance. The epicycloid, which gives the true curve to the teeth of the bevel gear, differs in this way from that of the spur-wheel, namely, that one cone is rolling upon the surface of the other, while their summits coincide.

(40.) In reference to Fig. 1, Plate VII., A C and B C are the axes or the centres of the wheels, D E and E F their proportional diameter or pitch lines. D E represents a wheel of 18 inches diameter × 36 teeth × $1\frac{9}{16}$ inch pitch × 4 inches wide on the face, and E F a wheel of 3 feet $1\frac{1}{2}$ inch diameter × 75 teeth of the same pitch and the same width.

(41.) After the pitch lines have been set out, draw through the centre C the lines D C F and C E, the proportional cones of the wheels rolling on the surface of the other. It may be now remarked that all the different points of the teeth, and the rims defined by R, have C for their common centre. This being followed up so far, set on the pitch line the breadth (here 4 inches) from D to G, and carry it on to each wheel; then draw this breadth at right angles to the line D C F and C E, and mark the height of the tooth and the thickness of the rim R, and draw each point, as aforesaid, to the centre C.

(42.) This being done, draw the eyes, the bosses, and likewise the arms marked respectively *a b c*, which will further be shown in preceding plates. The size of the eye and the boss will all depend on the calculation of the strains required. It may here be remarked that in practice the bosses of large wheels are cut or severed into several parts, on account of the contraction of the metal after being moulded and cast.

(43.) The setting out of the different wheels on Plate VII. is on the same principle as explained above; and to avoid needless repetition, as every remark that applies to the one applies to the other, we shall only proceed in stating that the wheels Fig. 2 are called "mitre wheels," as each wheel is of the same diameter, and forming an angle of 45°; Fig. 3, shows a pair of "bevel wheels" at $67\frac{1}{2}$°; and Fig. 4, also, a pair of bevel wheels at an angle of 45°. The different dimensions all being given, it will

be an easy task for a young mechanic to carry out these, or any other designs, for bevel wheels.

(44.) Plate VIII., Figs. 1, 2, 3. *The Construction of a Mitre Wheel.*—The side elevation (Fig. 1) is that of a mitre wheel of 8 inches diameter × 20 teeth × 1¼ inch pitch × 2 inches broad, which is drawn in section through A C, in Fig. 2, and in end elevation in Fig. 3.

(45.) As it is perfectly understood that A B C D represents the pitch line, on whose periphery the teeth are set out, and which also represents in Fig. 2 the base of a proportional cone, A C E, the angle at which the wheel has to work to that of the other, is here 45°, hence it is what is termed a "mitre" wheel. All the different points of the teeth have their common centre in E, and whose breadth are all lying in the frusta of such cone, here A C E.

(46.) When all these assisting lines are drawn, the number of teeth marked out in the elevation, proceed to the section in setting out, *a*, C, and C, *b*, the height of the tooth above and below pitch line, vertical to the frusta of the cone (here ⅜-inch and ½-inch), and also the thickness of the rim on the edge; carry point *a* to *a*, and point *b* to *b* in the elevation, and the protracted height of the tooth will be found. The form of the tooth in elevation now being set out by regular circles, the same as described in preceding pages on spur gear, begin to set out the breadth of the tooth in the section. C to C^1 here shows the breadth of 2 inches; the depth, a^1 b^1, of the tooth is, of course, proportioned by the lines running to the one common centre E; a^1 b^1, being parallel to *a* and *b*, or, which is the same thing, vertical to C E. These points, a^1 and b^1, being carried over to a^1 and b^1 in elevation, will show the protracted breadth and depth of the tooth. After connecting the inside and the outside of the tooth by

straight lines, all of whose inclination run to the centre E, draw the circle F, F^1, showing the depth below the bottom of the tooth, or the face of the body of the wheel. The dotted circles represent the boss which is tapered, on account of drawing the pattern easier out of the sand when moulding. The end elevation will readily be understood, though the assisting lines are not drawn; however, working together, the section and the elevation, the diameter of the wheel, the height and the breadth of the teeth, will all have to correspond; the position of each tooth will be found by carrying it over from the elevation.

(47.) Plate IX., Figs. 1, 2, 3, 4. *The Elevation and Plan of a Bevel Pinion, and also the Same Set at an Angle.*—The drawing of the pinion, Fig. 1, Plate IX., is a mitre wheel, 6 in. diameter × 16 teeth × $1\frac{3}{16}$" pitch × 2 inches wide, and the setting out is similar to the spur-wheel pinion, explained on Plates III. and IV. It only differs from these, that it is a conical wheel, its teeth having a common centre in C (Figs. 1, 2). The pitch line in Fig. 2, represents the base of a cone, A B C and A B D. On the former, the breadth of the tooth is set out, and on the latter, the height of the tooth, and the thickness of the rim, and, being a mitre, all angles are at right angles.

(48.) The elevation and plan being set out to dimensions given, the skew view of the pinion in Fig. 3 is found by determining on an angle for Fig. 4; and Fig. 2 being copied on such angle, and brought up to the elevation, on to the centre line, A B, each centre and every point will be found by drawing one view with the other.

(49.) Imagining, therefore, the wheel turned on one and the same plane, the point C, the common centre for the teeth will lie now in the elevation (Fig. 3) at C;

and all the lines for the teeth must be drawn to this point, instead of the centre in Fig. 1. The finding of the ellipse for the pitch line, would be a repetition of Plate III., and is therefore omitted, to try the young learner's own skill. The dotted lines will show him how to find the teeth in all the four views.

(50.) Plate X., Figs. 1, 2. *The Bevel Wheel and Pinion*—Plate XI., Figs. 1, 2, 3. *Bevel Wheel with Skew Teeth.*—The principal dimensions of the pair of wheels in plate are the following: Wheel, 2 feet diameter, × 48 teeth × $1\frac{9}{16}$" pitch × 4 wide; pinion 1 foot diameter × 24 teeth × $1\frac{9}{16}$" pitch × 4 wide. Fig. 1 represents the side elevation, Fig. 2 the end elevation; the axes of the same are A C for the pinion, B C for the wheel; the pitch line of the former, E F, and of the latter, F G; and the common centre for the inclination of the teeth in C.

(51.) After the number of the teeth being pitched off, draw the shape of the tooth required, (*see* D), to determine the height above and below pitch line; draw the same on to the line H F I, which, of course, is at right angles to the line F C; and the principal lines for the teeth is then found, leaving a small space between tooth, face and face, so that they do not bind on to each other —in fact, to give them a little play, by not gearing too deep into each other, to avoid breakage. Having thus found the diameters of the top and bottom of the teeth, continue finishing the form of every tooth of wheel in Fig. 1, and of dotted pinion, Fig. 2; proceed in setting out the breadth of the wheels, and the inner pitch line is found as already described, and deal with the diameters of the same, as for the outer diameters, by setting out every tooth. Draw every point of the teeth of side elevations of Figs. 1 and 2, to their respective lines on the end views, and the shape of every tooth is arrived at.

The dimensions of the remaining parts are given, and require no further explanation, besides observing the key ways, which always will have to be slotted in the strongest parts of the wheels, as seen in Fig. 1, opposite each rib of the arm.

(52.) Plates XII., XIII., and XIV. are given here as examples of the application of screws, wheels, etc., to practical machinery. Plates XII. and XIII. are working drawings of a screw or lifting jack, Fig. 5 beingthe elevation, Fig. 1 being the detail in larger scale of the head of screw at *a a*, Fig. 1, through which, to work the same, the lever *b b* passes; Fig. 2 is the section of Fig. 1, Fig. 3 the plan of the under side of Fig. 1, and Fig. 4 of Fig. 2. In Plate XIII. further details are given, Fig. 1 being the elevation of the part *c c* in Fig. 5, Plate XII.; Fig. 2 the section of same; Fig. 3 the plan of upper side of Fig. 1; Fig. 4 the plan of under side. Figs. 5 and 6 are diagrams illustrative of the development of the screw in Fig. 5, Plate XII. Fig. 7 is a drawing to illustrate the application of gearing to a machine used in the manufacture of cotton; *a*, spur-wheel, on the axle of which is a bevel wheel, *b*, driving the bevel pinion and shaft, *c*; *d d e* are driving pulleys or drums (*see* next Chapter) with driving belt, *f f*. Plate XIV. represents part of an apparatus used to raise the buckets of mortar from the ground level to the works going on at a higher level in the building of a railway viaduct. The buckets are raised by an endless chain passing over a pulley or drum at the high end, another at the low level—the axle of the lower drum is provided with a worm-wheel, which gears with the endless screw, *a a*, Fig. 1, Plate XIII., and which is carried by the vertical shaft, *b p*. This passes through the eyes of, and is supported by, the projecting brackets, *c c c*, secured by the bolts and nuts, *d d*, to the uprights, *e e e*. The vertical shaft, *b p*

receives motion through the bevel pinion, *f;* through the bevel-wheel, *g*, keyed on to the end of the horizontal shaft, *h h;* supported by the pedestals, *i i*, on the uprights, *e e*. The shaft, *h h*, receives its motion by means of the belt, *k k*, passing from the drum on the shaft, *l l*, of the engine, supported on pedestals, *u u*, and of which *m* is the fly-wheel. The pulley *k* passes over the lower pulley, *n n*, and upper pulley, *j j*. Figs. 2 and 3 are diagrams illustrating the development of the endless screw, *a a*, in Fig. 1. Fig. 4 is the plan of the bracket, *c d d*, in Fig. 1—*c* being the section in the line *a b*. Fig. 5 is a vertical section in a larger scale of the "step" *o* (Fig. 1), in which the wheel of the vertical shaft, *b b*, revolves; *a a* the bolt holes, in the base, by which the step is secured to the wood frame, *p p*, in Fig. 1. The "brass" is at *a b* (Fig. 5), and this is secured from turning round by the key *c*. Fig. 6 is an elevation of Fig. 5, and Fig. 7 a plan. Fig. 8 is part front elevation and part development of back of the bevel-wheel, *g*, in Fig. 1; Fig. 9 being part vertical section of the same. In the next Chapter will be found descriptions, with calculations connected therewith, of various parts of machines named in the foregoing paragraph, as of shafts, pedestals, pulleys, etc., etc. Fig. 18, Plate XV., illustrates part of the gearing for driving a corn mill—*a*, being the main shaft driven by the steam engine, or other motive power, in which the large bevel wheel, *b b*, is keyed; this gears with the bevel pinion *c*, keyed on the vertical shaft *d*, which is supported by the pedestal *e*. The main shaft carries also a pulley, *f*, which, by means of a driving belt, *g g*, gives motion by the pulley to the shaft of the flour-dressing machine. Figs. 19 and 21 are illustrations of gearing. Fig. 20 is part of a grinding mill, in which a double motion is produced; the vessel A, in which the material is to be operated upon, has a circular motion given to it by means of the bevel gear B B; the shaft of

B being moved by the pulley C; the grinding-stone, D, has a motion of revolution on its axis given to it by means of the pulley E working in the pedestal F.

CHAPTER IV.

DETAILS AND CALCULATIONS CONNECTED WITH SHAFTS, PEDESTALS, AND PULLEYS.

(53.) SHAFTS are divided into two classes—those for heavy work being termed "shafts," and those for light work, "spindles." In Fig. 16, Plate XV., we give an illustration of a crank shaft for a steam-engine. The part *a*, in which the shaft revolves, is termed its "gudgeons," "bearings," or "journals." The parts on which the wheels, or pulley, which the shaft has to support, are fixed, are termed "bosses," as *b*, Fig. 16. The "journals" are terminated by projections termed "ruffs," or "collars," as *a a*, Fig. 20. In Fig. 16 *a a* is a transverse section of the boss of the shaft at *b*, in Fig. 16. The boss of the shaft has longitudinal grooves, as at *a a*, cut at four points, sometimes only two, of its periphery; corresponding grooves, or slots, are cut in the eye of the wheel, which is then passed over the boss, and firmly fixed thereon by driving "wedges," "keys," or "cottars," in the grooves. Shafts are either "vertical," or "horizontal." In horizontal shafts the bearings, or journals, are as at *a*, Fig. 16. In Fig. 18, Plate XV., *d* is part of a vertical shaft, *i* being the "boss" on which to fix the wheels, and *j* the part in which the shaft revolves. The method of constructing the parts, in which the journals and bearings of shafts revolve, will be described in a succeeding paragraph. When the power of an engine, or other prime mover, is

to be transmitted to a considerable distance by means of shafts—where the distance is too long to admit of a shaft being made in one length—several lengths are joined by means of what are termed "couplings." In Plate XV., Fig. 17 is an illustration of a form of coupling, with round box. The two shafts, *c* and *d*, are terminated by pieces being cut out at *a* and *b*, so that when the two are joined together, they form the joint as in the figure, and which is known as the "half-lap." A round coupling box, *e e*, is then passed over and secured either by a pin, as *a*, passing through both, or by a "key," as at *a*, Fig. 12, Plate XV.

(54.) When two shafts are joined, it is sometimes requisite to have the means of quickly disconnecting them; so that while the motion of one is continued, that of the other may be arrested. By this contrivance, one part of a machine can be put in and out of motion as required. In this arrangement, one of the coupling boxes, as *c c*, Fig. 12, Plate XV., is capable of sliding backward and forward in a longitudinal direction upon the shaft, this being effected by having a projecting "rib," or "feather," *b* (Fig. 12, Plate XV.), fixed on the shaft, with a corresponding groove in the eye of the coupling box. Thus the box is capable of being moved along the feather; but partakes of the motion of the shaft, and consequently revolves along with it. The faces of the clutches, as *c c*, *f f*, Fig. 12, Plate XV., are provided with corresponding indentations, *d d*, and projections, *e e*; so that when the two are placed in contact, the motion of the one shaft is communicated to the other. Thus, let *h*, the driving shaft, revolve on its bearings, and *g* the driven shaft, also revolving on its bearings, as in the drawing the two coupling clutches are shown in contact, the motion of the shaft *h* is partaken of by the shaft *g*. By moving the clutch *c*, however, along the feather *b*, the projections, *d d*, are taken from the indentations, *e e*, and

the motion of *h* is no longer communicated to the shaft *g*. The part *i i* of the "sliding clutch" *c c* is loosely embraced between the fork of a lever, which, on being moved from right to left, moves the clutch backwards and forwards on the feather, and thus throws the shaft *h* in and out of gear as desired. Figs. 22 and 23, Plate XV., are two views of a universal joint, or coupling. This is used where the direction of one shaft is at an angle to that of another as the lying shaft *a a*, the ends being coupled together by the links *b b*. Another and very generally used method of engaging and disengaging machinery, is by the "fast and loose" pulley. The two pulleys are of equal diameter and width, and are placed on the same shaft, close to one another. One of these is allowed to revolve freely on the shaft, the other is fixed to it by means of a key. By passing the strap or driving belt from the loose to the fast pulley, the shaft receives the motion from the prime mover, and *vice versa*. The loose pulley runs in a "journal" made on the shaft. Shafts are sometimes required to move only in one direction, as in cranes; to prevent the shaft from running round in an opposite direction, the contrivance illustrated in Fig. 4, Plate XV., is used. To the end of the shaft, the ratchet *a* is fixed; the pawl *b* is jointed at *c*, so as to hang loosely, and to keep in contact with the teeth of *b*, preventing the ratchet from moving in one, but allowing it to move in the other, direction.

(55.) Shafts, when working horizontally, are supported by what are called "pedestals," or "plummer blocks," as in Figs. 1, 2, and 3, Plate XV. Fig. 1 is an elevation of a plummer block, of which Fig. 2 is the section. The journal of the shaft, as *a* is embraced by "bushes," or "brasses," *e e;* these being made in two parts, the lower of which rests in a hollow part made in the lower part of the block, which is bolted to the framing of the machine by the bolts and nuts, *f f*, Fig. 1, which pass

through the bolt holes, *g g*, in Fig. 2. The upper brass, *e*, is embraced by the hollow part made in the cap of the block, *b b;* the cap being secured by the bolts and nuts, *d d*. The cap is finished with a small depression or hollow, *i*, Fig. 2, and communicates with a hole bored through the cap *b*, and upper brass *e;* through this oil is led to lubricate the shaft *a*. Shafts working vertically are supported at their lower ends by "steps," which are carried by blocks or brackets, as *e e*, Fig. 18, Plate XV. At *o*, in Fig. 1, Plate XIV., the "step" is shown supporting the vertical shaft, *b p;* Figs. 6, 7, and 8 being the details, for the description of which see the description of Plate XIV. To steady vertical shafts, they are sometimes supported in brasses, carried by projecting brackets, as *c c c*, Fig. 1, Plate XIV. When shafts are placed so as to run horizontally below a ceiling, the bearings are suspended from it, and are termed "hangers," or "gallows." Fig. 13, Plate XV., is a side elevation of a "hanger." Shafts are sometimes carried horizontally along the face of a wall. The bearings in this case are supported by "brackets," somewhat as at *b b*, in Fig. 1, Plate XIV.

(56.) Pulleys for carrying driving belts are of various forms, with straight or curved arms, and with flat or slightly curved peripheries, as at C, in Fig. 20; or at Figs. 5 and 6, Plate XV.; or as in Figs. 14 and 15; or at E, in Fig. 20, Plate XV; that at E, in Fig. 20, being adapted for a flat driving belt, that in Fig. 15 for a rope or chain.

(57.) *Calculations connected with the various parts of Gearing illustrated in preceding paragraphs.*—In this paragraph we give sundry calculations likely to be of use to the student and practical mechanic; for some of which we are indebted to one or two scientific journals named.

(*a*) Shafts are divided in practice into "prime movers," and "secondary movers;" the prime movers being the shafts which give off the first power in the steam engine;

secondary movers being shafts to which this first motion is communicated. Shafts are now nearly always made of cast-iron and wrought-iron. Cast-iron shafts being not only heavier than wrought-iron ones, but more liable to fracture, through the sudden variations of strain to which they may be subjected, and through the smaller tenacity and flexibility which they possess, wrought-iron shafts are fast superseding them. Shafts are subjected to the strains of torsion, which tends to weaken or break them, through the twisting of their fibres; and lateral or transverse strains, which tend to break them across, as a beam is broken by being overloaded. (1.) In computing the diameters of shafts, the horse-power which they are to transmit, and the number of revolutions which the shaft is to make per minute, are necessary to be known. For wrought-iron prime-mover shafts, the diameter may be found by extracting the cube root of the result obtained by dividing the horse-power which the shaft is to transmit by the number of revolutions it is designed to give out, and then multiplying the cube root so found by seven. For wrought-iron "secondary movers" the same rule applies. The final multiplier being five, or five and a-half. For "prime-mover" shafts in cast-iron the multiplier is seven and a-half; and for second shafts in cast-iron the multiplier is six. (2.) In practice, as a rule, the diameter of "first" shafts is double that of "second" shafts. The length of the "neck," or "journal," of a shaft varies in practice as the diameter increases. Some makers give a length of neck equal to one and a-half times the diameter. For small shafts, as those of two, two and a-half, and three inches in diameter, the length of neck may be twice its diameter. As the diameter increases, the length may be less in proportion, as, for example, the length of neck, of which the diameter is three and a-half inches, may be six and a-half inches in place of seven, as

above; if four inches diameter, the length may be seven; if five, eight; if six, nine; if eight, twelve; if ten, fourteen and a-quarter; if eleven, fifteen; and a twelve-inch diameter neck may have a length of sixteen inches. (3.) In computing the diameter of a round shaft to resist torsion, the data required are "the force or weight applied to the end of the lever, or the radius of the wheel or pulley with which the force is applied, and the length of this lever or radius of wheel or pulley,"—then multiply the weight or force in pounds by the length of the lever or wheel in inches, divided by 1700, if for a wrought-iron shaft; 1500 for cast-iron; 3200 for cast steel; 425 for brass; and 460 for gun-metal,—and take the cube root of the quotient thus obtained, which will give the diameter in inches. (4.) In computing the strength of shafting to resist lateral or cross-breaking strain, the length in feet of the shaft supported at both ends, is to be multiplied by the weight in pounds, applied at the centre of the shaft, and divided by 700 if the shaft is of wrought-iron, and 500 if of cast-iron,—the cube root of the quotient giving the diameter of the shaft.

(*b*) In designing the half-lap-couplings, as in Fig. 17, Plate XV., the following may be taken as approximate dimensions: If the diameter of coupling is three inches, the outside diameter of the box, *e e*, may be six inches, the length of this the same, and the length of the lap, *a*, two, or two and a-quarter inches; as a general rule, diameter of box, *e e*, twice that of shaft, *c d*; length of box, thrice; and length of lap two-thirds the diameter of the coupling at *a*. If, in place of a pin, as at a^1, the coupling-box is fixed on by a key, as at *a*, Fig. 7, Plate XV., then the width of the key should be one-fourth of the diameter of the shaft, and its mean depth one-half of the width. There is no taper in a "feather," as at *b*, Fig. 7, Plate XV.,—the depth of which is equal to its width or thickness.

(*c*) In designing pedestals, the thickness of cover, *b b*, Fig. 2, Plate XV., may be found by multiplying the diameter of the neck, or journal of the shaft (or, which is the same thing, the diameter [interior] of the brasses, *a*) by ·4, the thickness of the sole plate, *c c*, being found by multiplying diameter of *a* by ·3, and the diameter of the bolts *d d*, by multiplying *a* by ·25. For the brasses, as in Fig. 2, or in Fig. 9, Plate XV., the thickness of the metal at the bottom of the brass is obtained by multiplying the diameter of the journal, as *a*, Fig. 2, Plate XV., in inches, by 0·12 × 0·15. The thickness of the metal at the sides is three-fourths of the thickness at the bottom.

(*d*) The degree of convexity of pulleys, as Fig. 6, Plate XV., is obtained by making the rise in the centre half an inch in height for every foot of breadth the pulley has. When the diameter of the driving pulley and its velocity are known, the velocity of a driven pulley, of which the diameter is known, may be ascertained by multiplying the velocity of the driven pulley by its diameter, and dividing the result by the diameter of the driven pulley, the quotient is the velocity of driven pulley. To find the width of a driving belt, the thickness of which is three-sixteenths of an inch, the strain which is upon the belt is to be known, and this is divided by 50, which gives the width.

(*e*) From *The Scientific American* we take the following on pulleys, from the pen of Mr J. H. Cooper, of Philadelphia:

"The width of a certain belt is eighteen inches; speed of same, 1500 feet per minute; angle of belt with horizon, 45°; distance between centres of drums, twenty-five feet; diameter of driving drum, eight feet; diameter of driven drum, four feet. When this belt transmitted twenty-horse power, it worked quite freely; when the power was increased to twenty-five horse, it was necessary to make the belt quite tight, and when the power was increased to twenty-eight horse, it was necessary to apply

a tightening pulley, which caused the journals of the driven shaft to 'heat.'

"From the above data I have deduced the following formula, which will serve as a guide for determining the width of belts:

$$\frac{H\ P \times 3\frac{2}{5}}{\text{D}} = \text{width of belt in inches.}$$

"Di. small pulley in ft.

"If we assume this belt to transmit $22\frac{1}{2}$ horse power we shall then have a constant travel of 100 square feet of belt per horse power per minute.

"An eight-inch belt running 100 feet per minute will give one horse power. Hence we have

$$B = \frac{P\ 800}{V}$$

$$P = \frac{BV}{800}$$

$$V = \frac{P\ 800}{B}$$

"This rule gives $66\frac{2}{3}$ square feet per minute per horse power.

"One hundred square feet of belt per minute per horse power is considered an ample allowance; in many cases one-half will be sufficient.

"A twelve-inch belt running on a $5\frac{1}{2}$ feet pulley, at forty-five revolutions per minute, will carry twelve horse power. This rule gives sixty-four square feet of belt per minute per horse power.

$$W. = \frac{350\ H\ P}{D \times \text{rev. per min.}}$$

"In which W = width of belt in inches, and D = diameter pulley in feet. This rule gives 91·63 square feet per minute per horse power, and thirty pounds per inch-width of belt.

"Averaging these rules, we have about eighty square feet of belt per minute per horse power.

"Experiments have been made to test the comparative 'slipping' tendencies of leather and vulcanized rubber belts, which proved the superior adhesive qualities of the leather, but did not go any farther. It is not adhesion alone we want to prove the better belt; beyond a certain amount it is rather an injury to the belt than an advantage in its use, for 'slipping' is to be preferred to abrasion, when rapid destruction of the belt would result from the closeness of its sticking—an infirmity to which rubber belts are liable.

"Belts which are repeatedly shifted should be of good leather,

as the edges are almost constantly rubbing against the shifting device, and if of rubber they will wear away with great rapidity."

Another correspondent of the same Journal, who has largely experimented upon the subject of belts, has the following as the rules of practice which he has deduced from them, since following which he says he "never has had a single failure:"

"I always put the side of the belt which transmits the power on the bottom when the power is given out horizontally; in that position the slack side is where it should be—on the top; where the tightener—if one is used—should be. If power is transmitted vertically, I always put on a swinging tightener on the slack side, which operates by falling to a horizontal position.

"I submit belts to fifty pounds per inch in width of tension, which is made up of the power to be transmitted and their own weight. Where the distance between centres of pulleys give sufficient tension, no tighteners are used. Where they are too close together I use tighteners—no curve on their face—of as large diameter as is convenient. I count on getting twenty pounds of adhesion from fifty pounds of tension in all cases.

"I count the power to be transmitted as so many pounds at the end of a lever, of the length of the radius of the pulley—the velocity being in the calculation by which the number of pounds were got—and divide the number of pounds by twenty, the adhesion, for the width of the belt in inches. I then see if the distance between centres will give the necessary tension to make the first calculation good, if not, the remedy is a tightener, if the distance cannot be increased. If the width of belt got by these means is too great, then the diameter of the pulley—or the radius, which is the same—must be increased; by doing so, the number of pounds to be transmitted at the end of the lever is diminished. I again divide by twenty; and if the width is again too great, I again increase the lever until I get it down to what I want it; and the whole proceeding is as certain as it is simple."

(*f*) On the strength of the teeth of wheels, a correspondent of the *Engineer*, "A. B., Ex.," has the following, which we do our readers a service by extracting:—

"I herewith send you a rule for the strength or the power they will transmit. I adopted it some seven years since, and find it does far better than any rule I have yet seen. As an example, three-in. pitch is usually taken by all who have written

or published anything on the subject, and at a velocity of three feet per second. Tredgold gives it fifteen H. P.; 'The Engineer's Assistant,' 14·5 H. P.; Hick, ten H. P.; Roberton, ten H. P.; Carmichael, 9·91 H. P.; Farray, 13·5 H. P.; Buchanan, 9·4 H. P. These are all nearly correct, taking their data from wheels actually in use, and going at or near about three feet per second. I find for general use, Tredgold's data and 'The Engineer's Assistant' the best, with the correction proper for the velocity.

(A.) TABLE OF STRENGTHS OF WHEELS, H. P. AT THREE FEET VELOCITY PER SECOND.

Pitch	¼	⅜	½	⅝	¾	⅞	1	1¼	1½	1¾	2	2½	3	3½	4	5	In.
Width	½	¾	1	1¼	1½	1¾	2	2½	3	3½	4	5	6	7	8	10	do.
Power	¼	⅜	½	¾	1	1·5	2·	3·	4·	5·	7	10·5	15·	21·	27·5	42·5	Tredg.
Do. .	·1	·26	·4	·66	·9	1·4	1·6	2·5	3·5	5·	6·25	10·	14·5	19·5	25·5	40·	E. A.

The breadth to be twice the pitch in all calculations for strength; any extra breadth is of no further use except for extending the bearing surface and lessening the wear. Practically, three times the pitch is the utmost limit. Fine-pitch broad wheels are very apt to strip gear, especially where put on slight shafting, which is the least deficient in lateral stiffness; sometimes whole teeth, and at others, portions, will break off diagonally with the radial line of tooth. Buchanan gives the best information on the teeth of wheels of any writer I have yet met with.

(B.) TABLE OF MULTIPLIERS FOR STRENGTHS OF WHEELS TO BE USED WITH TABLE A.

Vel. in Ft.	·1	·2	·3	·4	·5	·6	·7	·8	·9	1·0	1·5	Per Sec.
Mult. . .	·185	·26	·314	·365	·41	·45	·485	·515	·55	·57	·7	Mult.

Vel. in Ft.	2·	2·5	3·	4·	5·	6·	7·	8·	9·	10·	11·	Per Sec.
Mult. . .	·812	·913	1·	1·15	1·28	1·412	1·53	1·63	1·73	1·82	1·91	Mult.

Vel. in Ft.	12·	13·	14·	15·	16·	17·	18·	19·	20·	21·	Per Sec.
Mult. . .	2·	2·08	2·158	2·236	2·308	2·38	2·45	2·515	2·58	2·645	Mult.

Vel. in Ft.	25·	30·	35·	40·	45·	50·	60·	70·	80·	90·	100·	Per Sec.
Mult. . .	2·886	3·16	3·41	3·65	3·87	4·08	4·47	4·8	5·16	5·47	5·77	Mult.

"An example of the working of this table I now give: H. P. twenty, velocity ten feet per second: required the pitch.

"Horse power, ... 20

——— = 10·98 H. P., the strength

"Multiplier for ten feet = 1·82

at three feet velocity, the nearest to which in the Table A is 2½ inches pitch. Or say a wheel of three inches pitch, and a velocity of six feet per second, Table A, = 15 × 1·412 = 21·18 H. P.; according to the old established theory it would be thirty H. P. Another example: Thus, two inches pitch, at a velocity of ·5 feet per second, 7· H. P. × ·41 mult. = 2·87 H. P.; old system it would be 1·166 H. P. The strength does not increase in relative proportion with the velocity as usually supposed; and I believe that is the reason of the scales given varying as they ascend or descend from the three-inch pitch. The various experimenters have some tried finer wheels at a greater velocity, and others coarser ones at a slower velocity; for instance, the strength of one-inch pitch by the following authors, is—'Engineer's Assistant,' 1·6 H. P.; Tredgold, 2· H. P.; Hick, ·38 H. P.; Roberton, ·375 H. P.; Carmichael, 1·1 H. P.; and for four inches pitch—'Engineer's Assistant,' 25·5 H. P.; Tredgold, 27·5 H. P.; Hick, 24· H. P.; Roberton, 21· H. P.; Carmichael, 16· H. P. No doubt they are all right at one particular speed, at which they each took their data from; the extra wear on high velocities detracts from the strength, so does the vibration to which all fast-moving machines are subject to, and lessens with the reductions of the velocities, which I take to be as the square roots, from the same law which governs falling bodies. The Table B, before given, is calculated from the three-feet velocity—taking a velocity, say twelve, for instance, which divide by three, the normal one equals $4^2 = 2$, which is the multiplier for that velocity; any other multiplier may be made by the same process for any required or existing velocity."

(*g*) In the *Journal of the Franklin* (American) *Institute*, Mr J. B. Francis, C.E., has an elaborate paper, giving the results of extended experiments instituted to "ascertain the relative fitness of wrought-iron and steel for the *shafting* of a cotton factory." This paper, the reader will find *in extenso* in *Engineering* for August 23 and 30, 1867. We take from it the following:

" *Table of the greatest admissible distances between the bearings of continuous shafts, subject to no transverse strain except from their own weights.*

Diameter of Shaft, in inches.	Distance between bearings, in feet.	
	If of wrought-iron.	If of steel.
1,	12·27	12·61
2,	15·46	15·89
3,	17·70	18·19
4,	19·48	20·02
5,	20·99	21·57
6,	22·30	22·92
7,	23·48	24·13
8,	24·55	25·23
9,	25·53	26·24
10,	26·44	27·18
11,	27·30	28·05
12,	28·10	28·88

" In practice, long shafts are scarcely ever entirely free from transverse strains; however, in the parts of long lines which have no pulley or gears, with the couplings near the bearings, the interval between the bearings may approach the distances given in the preceding Table. Near the extremities of a line, the distances between the bearings should be less than are given in the Table. The last space should not exceed sixty per cent. of the distance there given, the deflection in that space being much greater than in other parts of the line. In shafts moving with high velocities, it will usually be necessary to shorten the distances between the bearings, as given in the Table, in order to obtain sufficient bearing surface to prevent heating.

" The following Table gives the power which can be safely carried by shafts making one hundred revolutions per minute. The power which can be carried by the same shafts at any other velocity may be found by the following simple rule:

" Multiply the power given in the Table by the number of revolutions made by the shaft per minute; divide the product by 100; the quotient will be the power which can be safely carried.

Diameter in Inches.	Horse-power which can be safely carried by shafts for prime movers and gears, well supported by bearings, and making 100 revolutions per minute; if of			Horse-power which can be safely transmitted by shafts making 100 revolutions per minute, in which the transverse strain, if any, need not be considered; if of		
	Wrought-iron, computed by formula (13).	Steel, computed by formula (16).	Cast-iron, computed by formula (20).	Wrought-iron, computed by formula (15).	Steel, computed by formula (18).	Cast-iron, computed by formula (22).
1·00	1·00	1·60	0·60	2·00	3·20	1·20
1·25	1·95	3·12	1·17	3·90	6·24	2·34
1·50	3·37	5·39	2·03	6·74	10·78	4·06
1·75	5·36	8·58	3·22	10·72	17·16	6·44
2·00	8·00	12·80	4·80	16·00	25·60	9·60
2·25	11·39	18·22	6·83	22·78	36·44	13·66
2·50	15·62	24·99	9·37	31·24	49·98	18·74
2·75	20·80	33·28	12·48	41·60	66·56	24·96
3·00	27·00	43·20	16·20	54·00	86·40	32·40
3·25	34·33	54·93	20·60	68·66	109·86	41·20
3·50	42·87	68·59	25·72	85·74	137·18	51·44
3·75	52·73	84·37	31·64	105·46	168·74	63·28
4·00	64·00	102·40	38·40	128·00	204·80	76·80
4·25	76·77	122·83	46·06	153·54	245·66	92·12
4·50	91·12	145·79	54·67	182·24	291·58	109·34
4·75	107·17	171·47	64·30	214·34	342·94	128·60
5·00	125·00	200·00	75·00	250·00	400·00	150·00
5·25	144·70	231·52	86·82	289·40	463·04	173 64
5·50	166·37	266·19	99·82	332·74	532·38	199·64
5·75	190·11	304·18	114·06	380·22	608·36	228·12
6·00	216·00	345·60	129·60	432·00	691·20	259·20
6·25	244·14	390·62	146·49	488·28	781·24	292·98
6·50	274·62	439·39	164·78	549·24	878·78	329·56
6·75	307·55	492·08	184·53	615·10	984·16	369·06
7·00	343·00	548·80	205·80	686·00	1097·60	411·60
7·25	381·08	609·73	228·65	762·16	1219·46	457·30
7·50	421·87	674·99	253·13	843·74	1349·98	506·26
7·75	465·48	744·77	279·29	930·96	1489·54	558·58
8·00	512·00	819·20	307·20	1024·00	1638·40	614·40
8·25	561·52	898·43	336·91	1123·04	1796·86	673·82
8·50	614·12	982·59	368·47	1228·24	1965·18	736·94
8·75	669·92	1071·87	401·95	1339·84	2143·74	803·90
9·00	729·00	1166·40	437·40	1458·00	2332·80	874·80
9·25	791·45	1266·32	474·87	1582·90	2532·64	949·74
9·50	857·37	1371·79	514·43	1714·74	2743·58	1028·86
9·75	926·86	1482·98	556·12	1853·72	2965·96	1112·24
10·00	1000·00	1600·00	600·00	2000·00	3200·00	1200·00

"The diameters of shafts of wrought iron and steel, to transmit the same power, are in the ratio of the cube root of 50 to the cube root of 31·25, or as 1 to 0·855. The weights of the shafts will be as the squares of the diameters, or as 1 to 0·731. The power required to overcome the friction of the shafts in their bearings, assuming that the co-efficient of friction is the same for wrought iron and steel, will be as the products of the weights into the velocities of the rubbing surfaces. The number of revolutions in a given time being the same in both, the velocities of the rubbing surfaces will be as the diameters, and the weights will be as the squares of the diameters; the power required to overcome the friction will therefore be as the cubes of the diameters, or as 1 to 0.625. That is to say, the power which must be expended to overcome the friction of a steel shaft is five-eighths of that required to overcome the friction of a wrought-iron shaft of equal strength.

"The superiority of steel to resist transversal strain is much less than to resist torsional strain. The relative diameters of wrought-iron and steel shafts, to resist equal transverse strains, exclusive of their own weights, are inversely as the fourth roots of the respective values of E, or as

$$\left(\frac{1}{3500000}\right)^{\frac{1}{4}} \text{ to } \left(\frac{1}{3800000}\right)^{\frac{1}{4}}, \text{ or as } 1 \text{ to } 0.98.$$

That is to say, steel shafts, to offer the same resistance to external transverse strains, may be two per cent. less in diameter than wrought iron shafts. The weights of such steel shafts will be about four per cent. less than the weights of wrought-iron shafts of equal stiffness; and the power required to overcome the friction of the bearings will be about six per cent. less."

CHAPTER V.

A SELECTION OF GEOMETRICAL PROBLEMS USEFUL TO THE MECHANICAL DRAUGHTSMAN AND DESIGNER.

(58.) PLATE XVI., Fig. 1. *To find the centre of a given circle*, A B C.—Draw any chord, A B, in the circle;

bisect the chord by the perpendicular, C D, which is a diameter; then bisect C D in the point F: this point is the centre of the circle.

(59.) Plate XVI., Fig. 2. *To describe a circle through three given points*, A B C.—Join A B and B C, bisect A B and B C by the perpendiculars, *a* D and *b* D, then with D as centre, and D A as radius, describe the required circle.

(60.) Plate XVI., Fig. 3. *To draw a tangent to a circle from a given point without it.*—Let A be the given point, and C D E the circle; join A B on A B; describe semi-circle A C B, cutting the given circle in C; draw A C the required tangent.

(61.) Plate XVI., Fig. 4. *Part of the circumference of a circle being given, to find the centre from which the remainder may be described.*—Let A B C be the part given, and A B C any three points therein, from A and B, with radius A B; describe arcs cutting in D E, and from B C with B C; describe arcs cutting in *a b;* through these draw lines cutting in *m:* it is the centre required.

(62.) Plate XVI., Fig. 5. *On a straight line* A B, *to describe a pentagon.*—Erect the perpendicular B *c*, equal to half A B; join A C and make *c d* equal to B *c;* from A and B, with radius B *d*, describe arcs cutting in *e*, which is the centre of the circle A B F G H; the sides, B F, F G, G H, and H A, being made equal to A B, complete the pentagon.

(63.) Plate XVI., Fig. 6. *Upon a given straight line* A B, *to describe a hexagon.*—From B, with radius A B, make semicircle A D C; divide the semi-circumference, A D C, into six equal parts, the number of sides in

a hexagon; draw B E through the second division of the semicircle; bisect A B E in F, the centre of the circle A B E G; apply the distance B E six times round the circle A B G E, which will be the hexagon required.

(64.) Plate XVI., Fig. 7. *To describe a regular octagon upon a given straight line,* A B.—From the extremities of A and B erect the perpendiculars A E, B F; extend the given line to *k* and *b;* bisect the angles *k e, b c,* in H and C; draw A H and B C; erect the perpendiculars, H G and C D, equal to line A B; join D F and G E, which will give the octagon required.

(65.) Plate XVI., Fig. 8. *To inscribe a pentagon in a given circle.*—Draw the diameter, A B, divide it into five equal parts, from A B with A B; describe arcs cutting in D through the second of the points from A; draw from D to C; join A C: it is the side required.

(66.) Plate XVI., Fig. 9*a*. *To inscribe a hexagon in a given circle.*—Draw the diameter, A B from A; with A C the radius; describe arc, cutting the circle in D E; join A D; it is the side required.

(67.) Fig. 9. *To inscribe an octagon in a given circle.*—Draw diameters, intersecting in E; bisect each of the quadrants thus obtained; join the points.

(68.) Plate XVI., Fig. 10. *To inscribe an octagon, or a square, in a given circle.*—Let A B C be the given circle; draw the diameters, A C and B D; join A B, B C, C D, and D A, these lines will form the square, A B C D; bisect the arcs, A B, B C, C D, and D A in the points *e f g* and *h;* join A *e*, *e* B, B *f*, and the octagon will be complete.

(69.) Plate XVI., Fig. 11. *To describe a square, as also an octagon, about a given circle.*—Draw the diameters, A B, C D; through the extremities of these diameters draw the lines, E C F, F B G, G D H, and H A E, at right angles to A B and C D, and intersecting at the angular points E F G and H, the figure E F G H is the circumscribing square; join E G and F H, cutting the circle in the points *a. b. c. d.;* also through these points draw the lines *c f, g h, k l, m n,* and at right angles to their respective radii, they will complete the octagon, which is described about the circle A D B C.

(70.) Plate XVI., Fig. 12. *Upon a given right line, as* A B, *to make any polygon from a hexagon to a dodecagon.*—Bisect the line A B in *o;* erect the perpendicular *o* I; from the point B describe the arc A C, then divide A C into six equal parts; if a heptagon is to be made from the point C, and distance C *m,* describe the arc *m* D; D will be the centre of the polygon. For an octagon, from the centre C, and distance C *n,* describe the arc *n* E; E will be the centre of the octagon. The same way for all the rest, adding one part each time.

(71.) Plate XVI., Fig. 13. *To describe an ellipse on a given line,* A B.—Divide A B into three equal parts from *c d,* with *c f;* describe two circles, cutting in *e* through the centre and the points of intersection; draw lines, *c f, d e,* from the point of intersection, as *e;* take to *f* in the compasses, and describe parts of circles, joining the small ones previously described, as *f f.*

(72.) Plate XVII., Fig. 14. *Method Second.*—Divide the line A B into four equal parts from *c d,* the first and third; describe with radius A C two circles; from *c d* with *c d* as radius describe arcs, cutting in *e* on both sides of A B; from *e,* draw through *d* to *g,* with *e g;* from

e with *e g*, describe parts of circles joining those previously drawn.

(73.) Plate XVII., Fig. 15. *To describe an ellipse, the diameters being given.*—Let A B, C D be the diameters, take C D, and from *a* lay it on A B to *f*; divide *f* B into three equal parts, with two of these, from *e*, lay on A B to *g*, make *e h* equal *e g*; from *h g*, with *h g*, describe arcs as at *m*; from *h g*, with A *h*, describe parts of circles A B; from *m* describe an arc as in preceding problem.

(74.) Plate XVII., Fig. 16. *An ellipse may be described without compasses, on a large scale, as follows.*—Let A B be the length of the proposed ellipse, and C D half its breadth; bisect A B in C, draw C D perpendicular to it; with A C, from D, cut A B in E and F; in D E F fix pins, fasten a cord round E, carry it round D, and fasten it firmly to F, take out the pin D, and substitute for it a pencil, or tracer, keep the cord tight, and from D toward A move the tracer, and from D to B half of the ellipse will thus be described.

(75.) Plate XVII., Fig. 17. *To describe the curve of an ellipse by means of points, of which the major and minor axis are given.*—"Let *a a* be the major, and *b b* the minor axis. With half of the line *a a* as radius, describe from the point C, as centre, an arc, cutting the major axis in the points *f* F; these form the foci of the ellipse. Mark on the major axis, between the foci *f* F, a number of points, as *g h i k*. Then from the point F as centre, with radius *a g*, describe arcs F *m*, F *m*, one on the upper, the other on the under side of the major axis A *a*; then from the point *f* as a centre, with the distance *f g* as radius, describe arcs cutting those described from the point F, in *m m*. Next, from point F as a centre, with distance A *h*, describe other arcs m^1 m^1; next, from

the point *f* as a centre, with distance *f h* as a radius, cut these arcs. Proceed thus, taking all the distances on the major axis between the foci *f* F, and a number of points, as *m m*", *m*'" *m*"', will be found through which a line may be drawn by hand, which will be the outline of the ellipse."

(76.) Plate XVII., Fig. 18. *An ellipse being given, to find its foci and diameters.*—Draw any two parallel lines, as from A B, C D, bisect them in E E; draw E E, bisect it in F, which is the centre of the ellipse; from this, with any radius greater than half the supposed conjugate diameter, draw the circle *h*, cutting the ellipse in H M; join H M, bisect it, and through the point of bisection and also through F, draw a line O O, this is the transverse diameter; through F perpendicular to O O draw a line *p p* meeting the ellipse, this is the conjugate diameter; bisect F O in S, make F S equal F S on both sides of the conjugate; S S are the foci.

(77.) Plate XVII., Fig. 19. *To describe an ellipse by lines intersecting each other.*—Let A C be the major, and D B the minor axis; draw A F and C G, each perpendicular to A C, and equal to D B; divide A D and the lines A F and C G each into the same number of equal parts in 1, 2, 3, and 4; then from E, through the division 1, 2, 3, and 4 on line A D, draw the lines E *h*, E *k*, E *l*, and E *m*; and from B, through the divisions 1, 2, 3, and 4 on the line A F, draw the lines 1, 2, 3, and 4 B, and the intersection of these with the lines E 1, 2, 3, and 4 in the points *h k*, *l m*, will be points in the curve. Plate XVII., Fig. 20. *Another Method.*—Let A C be the major, and B D the semi-axis minor. On the major axis construct the parallelogram A E F C, and make its height equal to line D B, divide A E and E B each into the same number of equal parts, and number the divi-

sions from A and E respectively; then join A 1, 1 2, 2 3, etc., and their intersections will give points through which the curve may be drawn.

(78.) Plate XVII., Fig. 21. *The two diameters* A B *and* C D *being given, to describe the curve itself through a number of points to be determined at the extremities of any numbers of diameters at pleasure.*—Through the extremity D draw E F parallel to A B; extend the line C O to G, and make it equal to A S or S B; upon G, with the radius G D, describe the circle H D K. Through the centre *s*, draw the lines S L, etc., at pleasure, respectively cutting the line E F as shown. Join the points just determined on the line E F with the centre G, and mark the points of intersection produced on the arc H D K at *e*, *m*, *n*, *o*, etc.; draw lines from H, *l*, *m*, etc., parallel to G D, until they respectively intersect the extremities of the diameter at A, L, M, N, etc. These points will be in the periphery of the ellipse, and a curve traced through them will describe the figure.

(79.) Plate XVII., Fig. 22. *To draw a parabola by intersecting lines, its axis, height, and ordinates being given.*—Let A C be the ordinate, and D B the axis, and B its vertex. Produce the axis to E, and make B E equal to D B. Join E C E A, and divide them each into the same number of equal parts, and number the divisions as shown in the figure. Join the corresponding divisions by the lines 1 1, 2 2, etc., and their intersections will produce the contour of the curve.

(80.) Plate XVII., Fig. 23. *To draw a parabola by intersections.*—Let A C be the base, and D B the height of the curve. On A C construct the rectangular parallelogram, A E F C, its height being equal to D B. Divide the side A E into any number of equal parts 1 2 3 E;

and the half of the base A D into the same number of equal parts. From these divisions raise the perpendiculars 1 *e*, 2 *f*, 3 *g*, etc., and intersect them by the lines 1 B, 2 B, 3 B; draw from the divisions in A E to the apex of the curve B. The points of intersection *e f g* are points in the line of the curve.

(81.) Plate XVII., Fig. 24. *To describe by arcs the hyperbola.*—The first axis of any two hyperbolas A a^1, and their foci F *f* being known, to find any number of points in the curves. On the indefinite line E G, make the point E H equal to A *a*, then from the foci with a radius greater than A *f* or F *a*, describe the indefinite arcs *e e*, then set off this radius on the line E G from E to 1, and take the difference H 1, and with that as a radius from the foci, describe other arcs cutting the first arcs in 11, which will be points 1 in the hyperbolas. In the same way take a radius E 2, and describe arcs from the foci as centres, and intersect them with other arcs having a radius equal to H 2, and so on for the points 3, 4. The intersections are points in the curve through which the hyperbola may be drawn.

(82.) Plate XVII., Fig. 25. *To describe a spiral on a line a b, of which c d is the width between the convolutions.*—Bisect *c d* on the point a^1. From a^1 with *a c* describe the semicircle *c d*. From *c* with *c d* describe the semicircle *d f*. From a^1 with $a^1 f$ describe the semicircle *f e*. From the point *e* with *e e* describe the semicircle *e g*. From a^1 with $a^1 g$ the semicircle *g h*, etc.

(83.) Plate XVIII., Fig 26. *To describe the cycloid curve.*—Let *d* be the centre of a circle, *b d a* its diameter, and *b c* a line at right angles to *b a*. Divide *a b* into 7 equal parts, and make the distance *b c* equal to 11 of these parts, the line *b c* will be equal to half of the circum-

ference of the circle *a b*. Divide the distance *b c* into any number of equal parts, as 7 on the diagram. From these draw lines perpendicular to *b c*. Through the centre *d* of circle *b a*, draw a line *e d* parallel to *b c*. From the points where the lines 6 *f* 5 *h*, etc., intersect the line *d e* as centres, describe circles of the same diameter as *a b*. Next divide the semicircle *h b t* into the same number of equal parts as the line *b c* is divided into. Now, with the distance *h m* from the point 1 on the line *c b*, cut the circle described from the centre *g* in the point *i*. Next, with the distance *h n* from the point 2, cut the circle described from the point d^1 in the point b^1; and so on till a series of points are obtained, as c^1, d^1, e^1, f^1, through which the curve is drawn by hand.

(84.) Plate XVIII., Fig. 27. *The epicycloid* differs in the cycloid in this, that it is generated by a point in one circle C rolling upon the circumference of another, as D instead of a level surface, as *a b c* in Fig 26. This definition of the curve will be understood by reference to the Fig. in which C is the generating circle, and D the fundamental, or that upon which it rolls, in describing the exterior epicycloidal curve A B C. If the generating circle, instead of rolling on the outside, were to roll within the interior circle or point in the former, would describe an interior epicycloid, or, as it is more recently termed, the hypocycloid, as in Plate XVIII., Fig. 28. *To describe the curve.*—Let *a* be the large and fixed circle, and *b* the rolling circle. Draw the diameter *d e*, joining the centres *b* and *a*; divide the semicircumference *c d* of the rolling circle into any number of equal parts, as 6. Next divide the semicircumference of the fixed circle *c e* into double the number of parts into which *c d* is divided. Through these parts draw the radial lines, as *a f*, etc. From *a* as a centre with the distance *a b* as radius, describe the semicircle,

b g. From the points where this cuts the radial lines drawn from *a*, describe circles equal to the rolling circle *c b d*. Take the distance *c i*, and from the point *f* cut the circle described from the centre *b* in the point *c*. Take next the distance *c j*, and from the point *u* cut the circle described from the centre *o* in the point *v*. Next, with the distance *c k* from the point *w*, cut the circle described from the centre *p* in the point *z*. With the distance *c l* from the point *y*, cut the circle described from the centre *q* in the point 2. Proceed thus till a series of points be obtained through which the curve may be drawn by hand.

(85.) Plate XVIII., Fig. 28. *To describe the curve known as the internal epicycloid.*—Let *a* be the centre of the fixed circle, *b* that of the rolling circle. Divide the semicircumference *c d* into any number of equal parts as 6, and the semicircumference of the fixed circle *c e* into twice the number of equal parts; through these draw from a radial lines. From *a* with *a b* describe the semicircle *b f*. Now, from the point *b* with the distance *c h*, cut the circle described from the point *n* in the point *j*. Next, with the distance *c o* from the point *l*, cut the circle described from the centre *q* in the point *m*. Next, with the distance *c s* from the point *p*, cut the circle described from the centre *u* in the point *r*. Next, with the distance *c w* from the point *t*, cut the circle described from the centre 3 in the point *v*. Then with the distance *c* 1, cut the circle described from the centre *x* in the point *z*. Through the points *j, m, g, v*, 2, and 6, draw by hand the curve, which will be one-fourth of the complete internal epicycloid required.

(86.) Plate XVIII., Fig. 29. *To describe the curve known as the conchoid.*—Draw any two lines, as *a, b, c, d*, at right angles to each other, mark off any number of

equal or unequal parts on the line *c d*, as *f, g, h, i, j, k, l*, and *m*. From the point *e*, with any distance less than *e g*, set off on each side of the line *a d* to the points *n o*. Make *f p* equal to *f q*, *g r* equal to *g s*, *h t* equal to *h u*, *i v* equal to *i w*, *d x* equal to *d y*. Do the same on the other side of the central line *a b*. Through the points draw by hand the curve *n, p, s, u, w, y*. This curve is called the inferior conchoid. Draw through the points *o, q, r, t, v, x* a curve which will be the superior conchoid.

(87.) Plate XVIII., Fig. 30. *To describe the curve known as the cissoid.*—Describe a circle of any diameter, as *b c*. Draw the diameter *b c*, and at right angles to it the line *d c e;* divide the line *c d* into any number of equal or unequal parts, and from these draw lines as *d a*, etc., to the point *b*. From *b* measure off to the point where the line *d b* cuts the circle; then from *d* with the same distance, cut the line *d b* in the point *f;* with the distance *b g* from the point *h* cut the line *b h* in *i*; with *b j* from the point *k* cut the line *b k* in the point *l*. Proceed in the same way with all the others, and draw the curve through the point *f, i, l, o, r, u*, and *x*.

(88.) Plate XVIII., Fig. 31. *To describe the curve known as the involute.*—Suppose a cord to be wound round the circumference of a roller, and to be unwound by taking hold of it at a certain point, keeping the cord fully extended, the point at which the cord is held by the fingers will describe a curve, which is the involute. Let *a b* be the roller, and *c* the point at which the cord leaves contact with it on being pulled up or unwound in the direction *c b*. Draw the diameter *b a d*. Divide the distance *b c* into any number of equal parts, as *g h*, etc., and through these draw radial lines, as *a c*. At the points where these lines touch the circle, as *e, f, g, h, i, j, k, l*, and *m*, draw lines at right angles to them, as *v m* to the

line *a m*. From the point *f* as a centre with the radius *f e*, cut the line *f o* in the point *o*. From the point *g* with the distance *g o*, cut the line *g p* in *p*. Proceed in the same way with the other lines, and through *o*, *p*, *q*, *r*, *s*, *t*, *y*, *v* draw the curve by hand.

DEFINITIONS OF SOME OF THE TERMS USED IN PRECEDING PROBLEMS.

A "parabola" is a curve produced by a plane cutting the axis of a cone in a line parallel to one side of the cone. It is the curve in which projectiles move, making allowance for the resistance of the air.

A "cycloid" is a curve produced by assuming a nail to be fixed at any point, *p* in the circumference of a circle *a b*, Fig. 26, Plate XVIII., which is made to roll along a straight *c p*; the curved line $c^1\ e^1\ f^1\ a$, which the nail *p* describes in the air while the circle revolves, is a common cycloid.

The "hyperbola" is a curve produced by cutting a cone with a plane when the section is made parellel to the axis, so as to make a greater angle with the base than it does with the sides of the cone. The "ellipse," or oval, is when the plane cuts the cone obliquely. This figure being that which the planets describe in their revolutions round the sun, ranks next in importance to the circle.

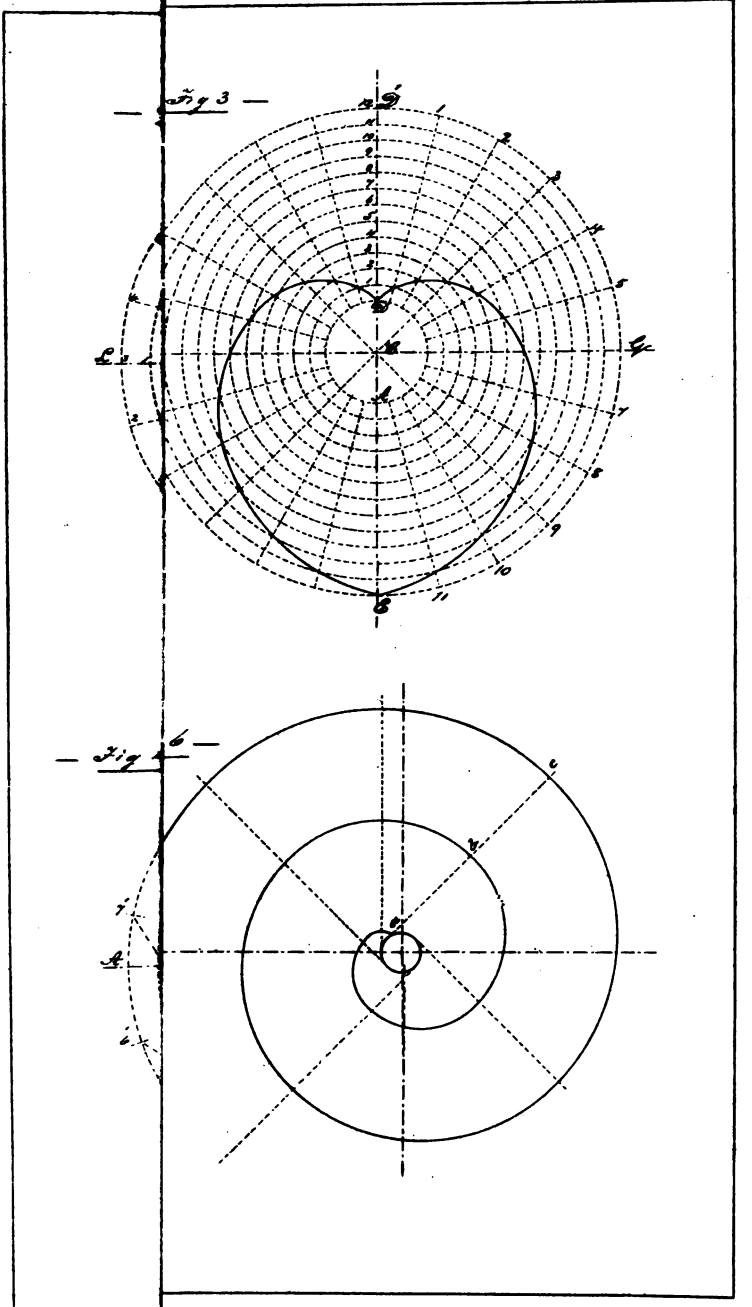
A "spiral," Fig. 25, Plate XVII., is a curve making any given number of revolutions round a fixed point without meeting itself. A line drawn from the centre of the spiral to the curve is called an ordinate.

The "hyperbolic spiral" is a curve passing through one extremity of arcs of equal length, drawn from any given point in a straight line, called the axis, and on the

same side of it. To draw the hyperbolic spiral, Fig. 32, Plate XVIII., draw lines forming equal angles round the centre, and fix upon one of these lines as the greatest ordinate; divide it into as many equal parts as the number of revolutions intended, and sub-divide each part into as many smaller equal parts as the number of angles make; the second or next ordinate one-part less, the third two-parts less, the fourth three-parts less, etc., than the first, and draw the curve through these points.

The "logarithmic spiral," Fig. 33, Plate XVIII., is where the ordinates form equal angles at the centre, and all the succeeding ordinates and cords form equal angles at the curves. The curve is also called the proportional spiral

Schenck & M'Farlane, Printers, Edinburgh.



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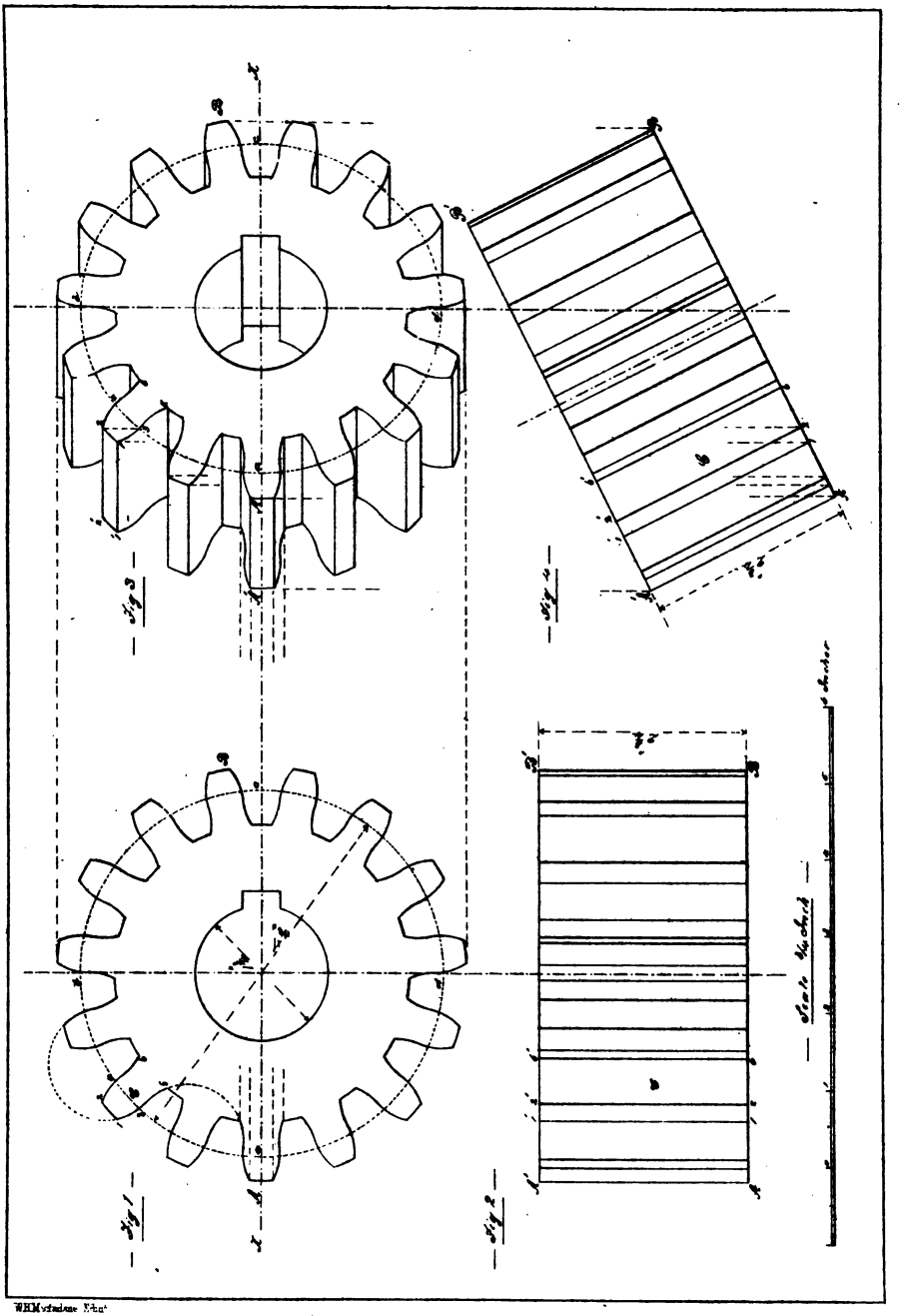

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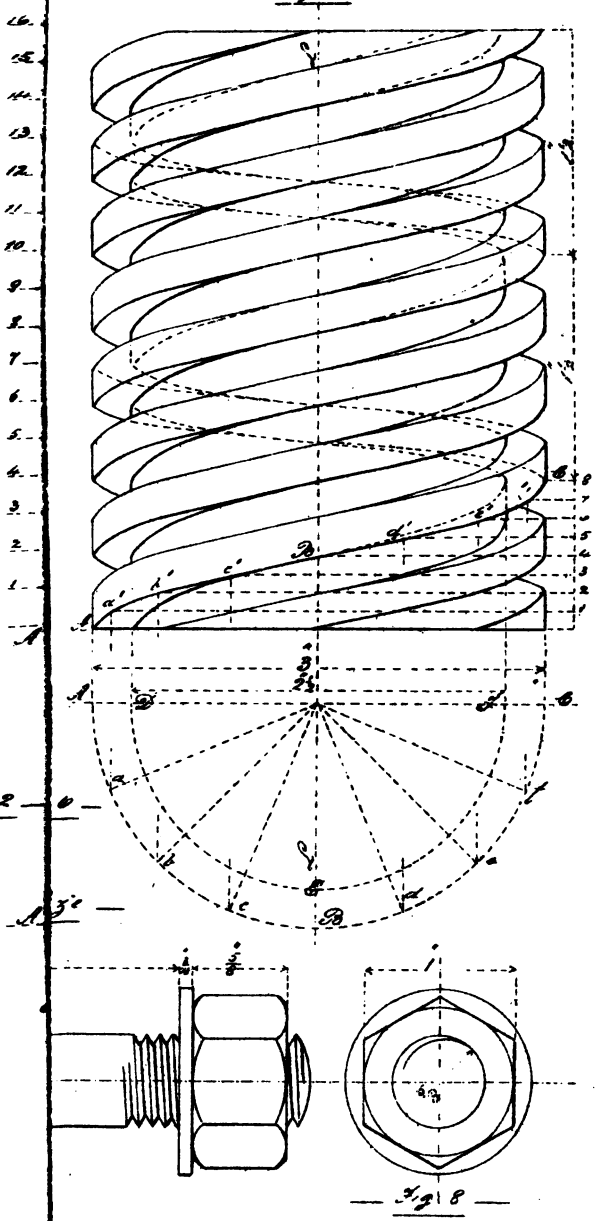
Fig 5
Fig 2
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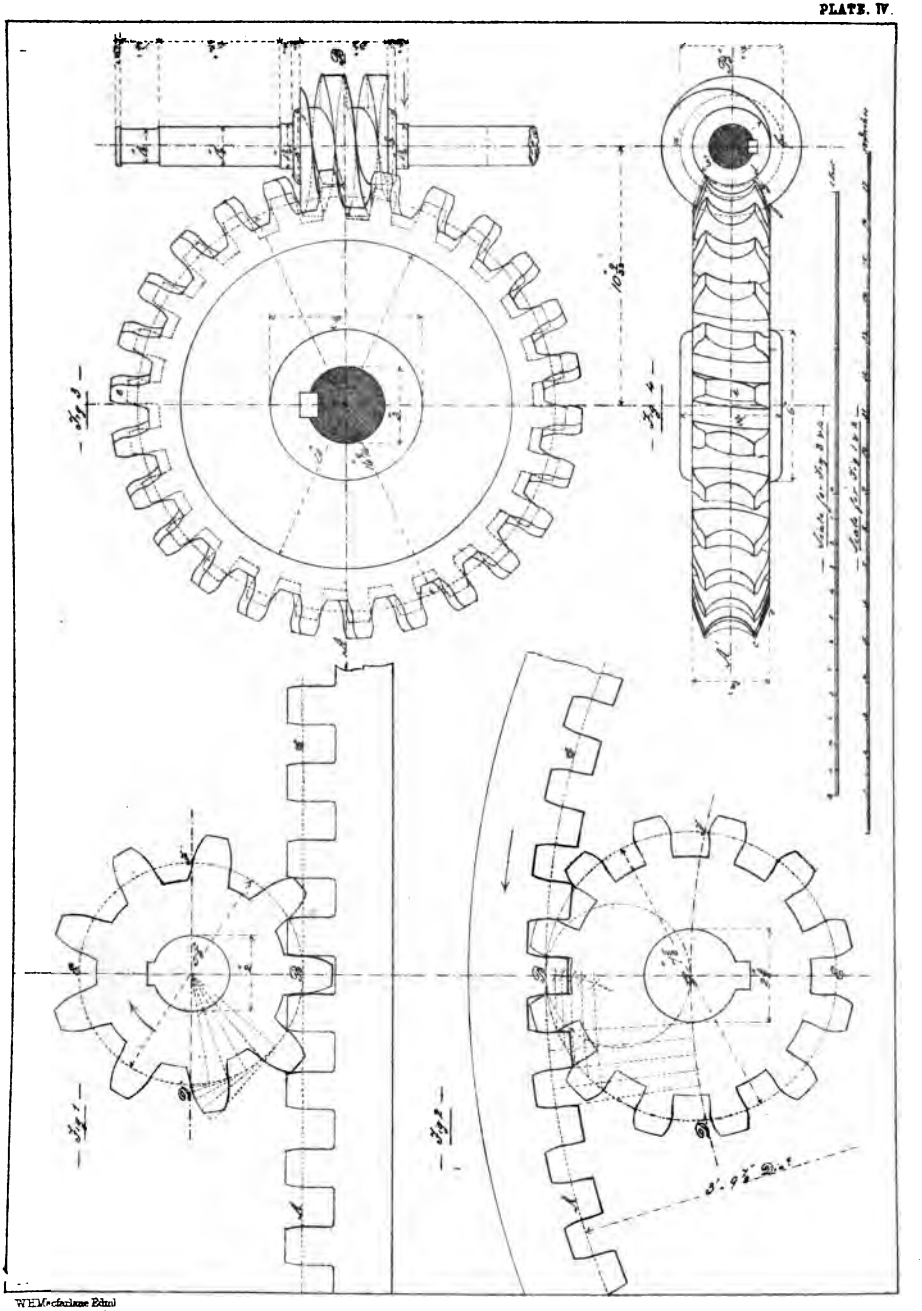

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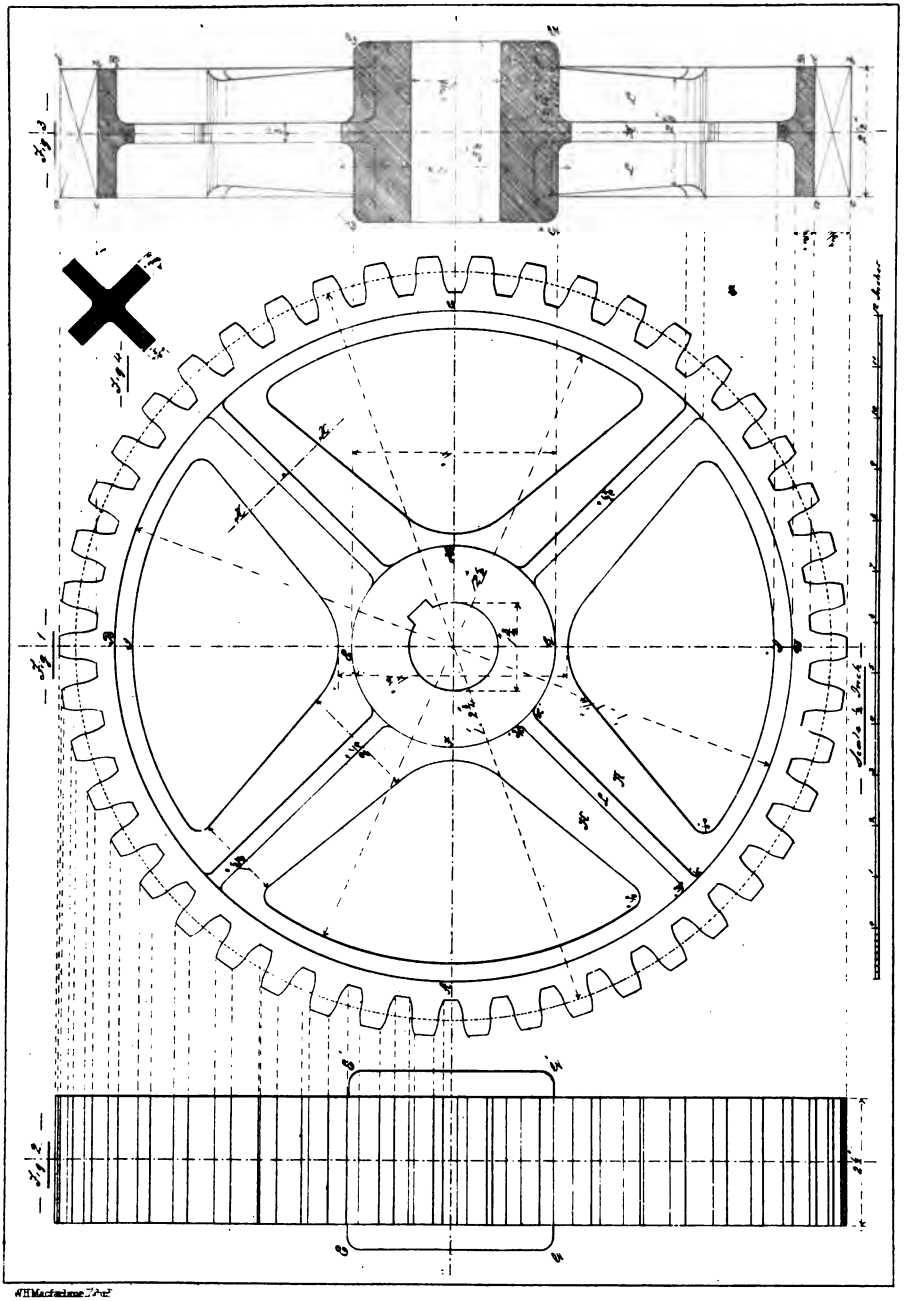
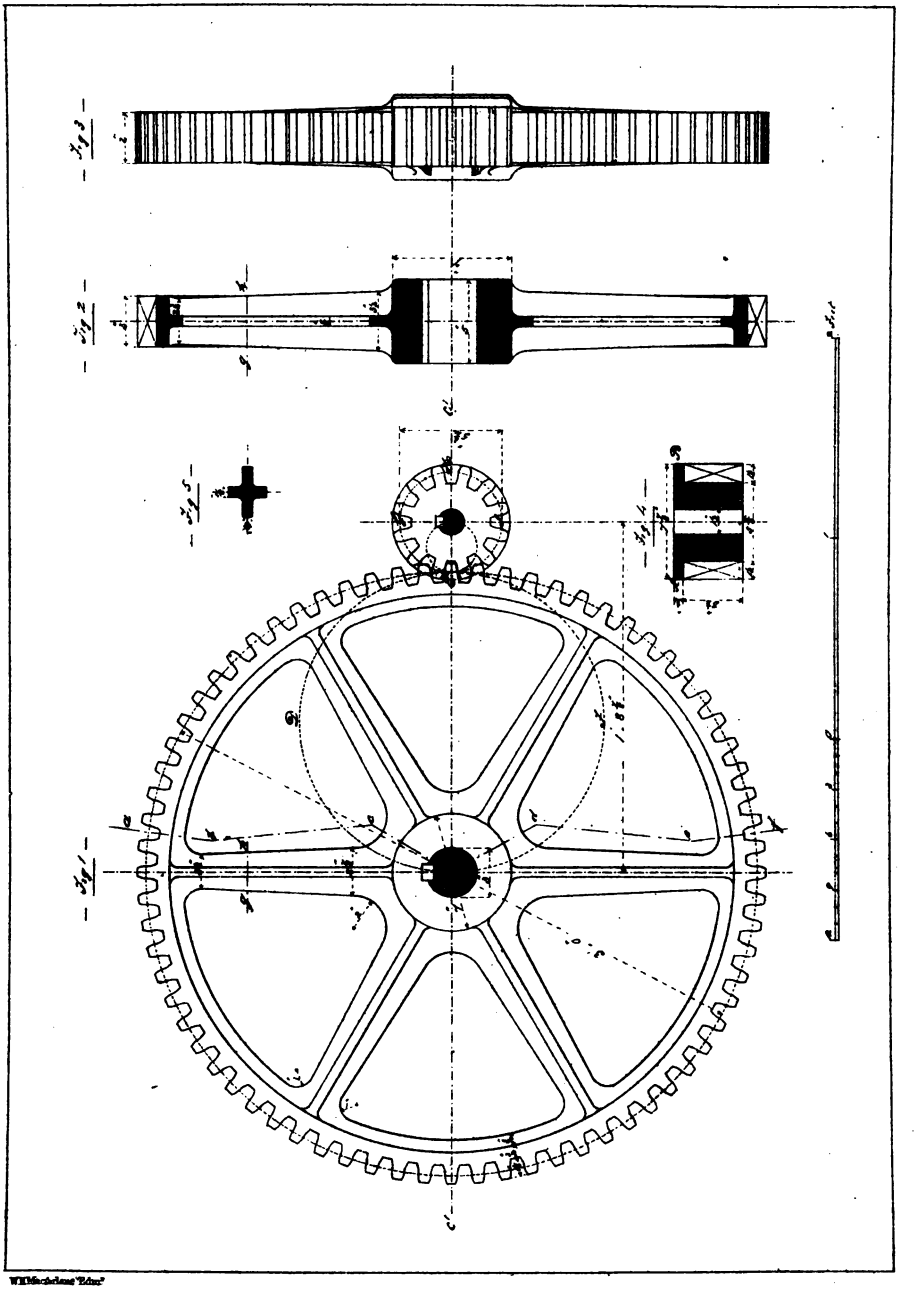
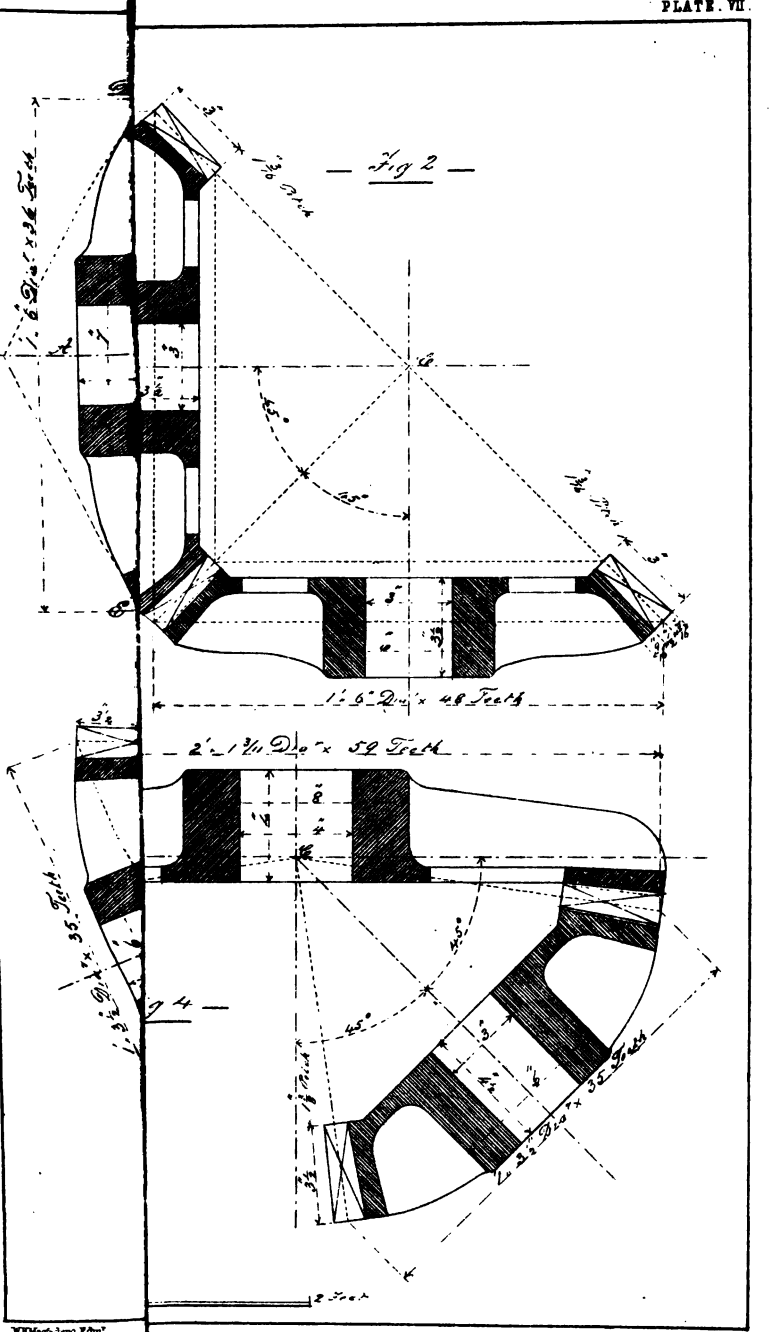


W.H.Macfarlane & Co.





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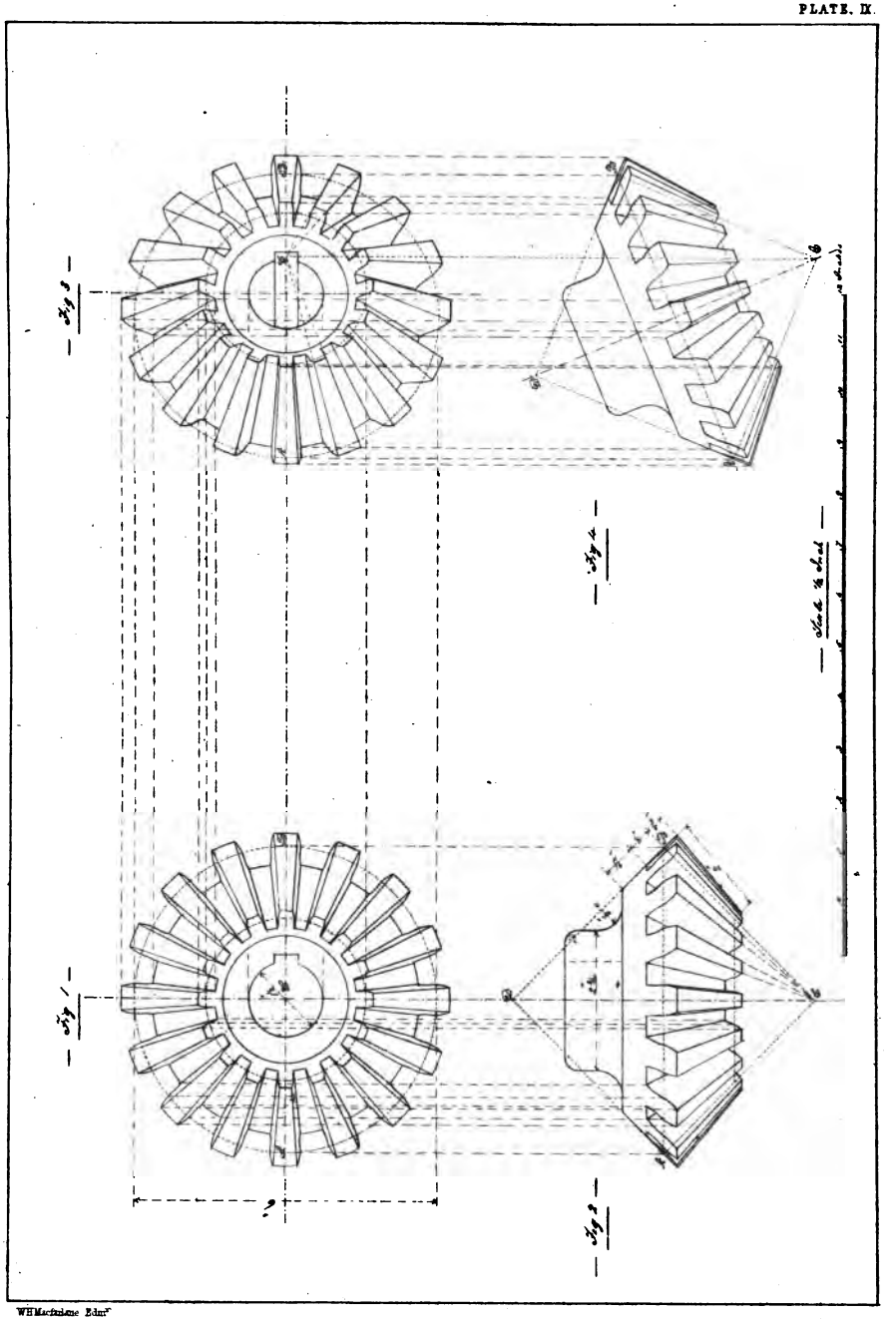

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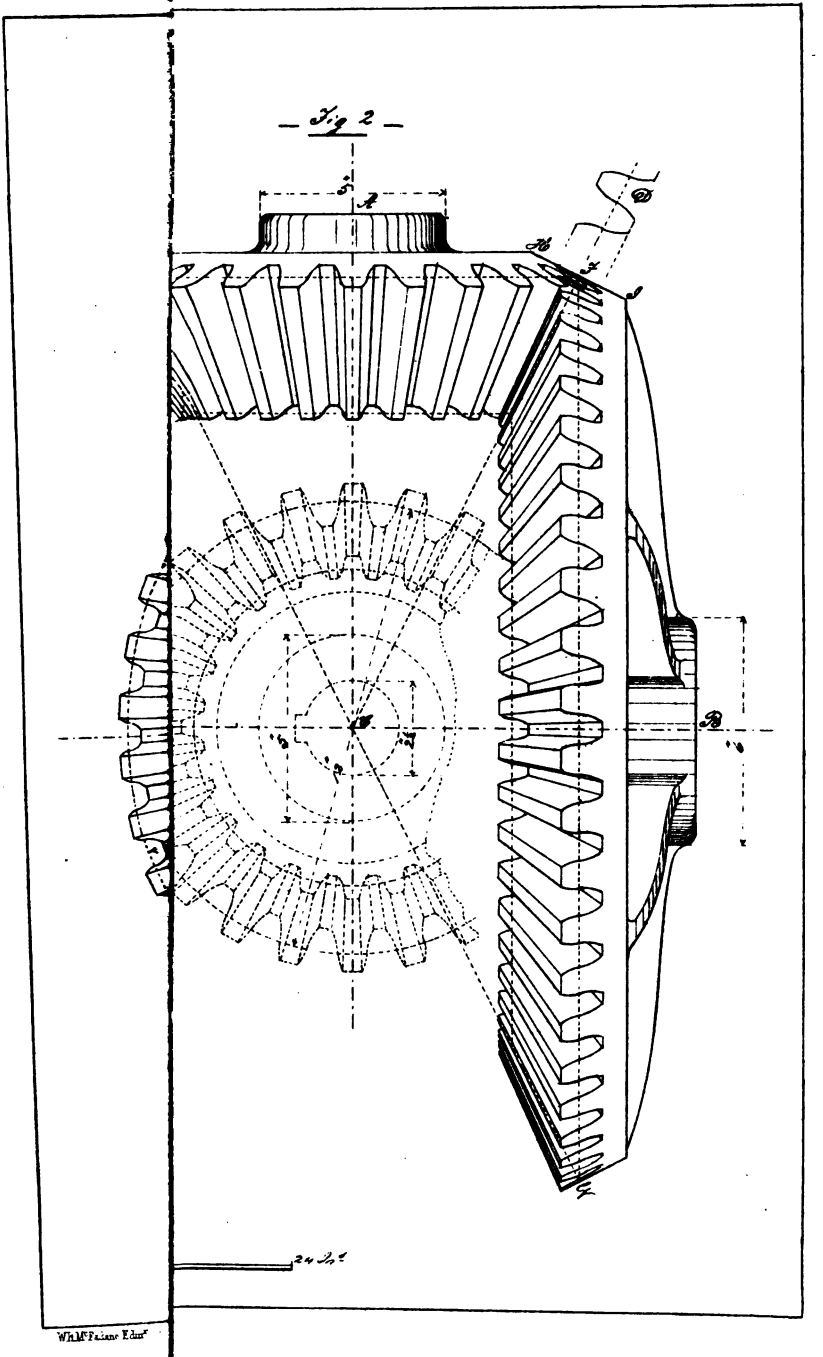
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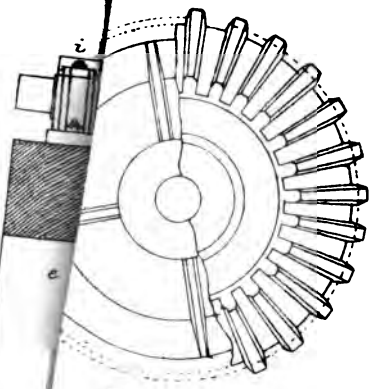

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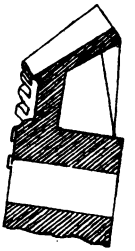

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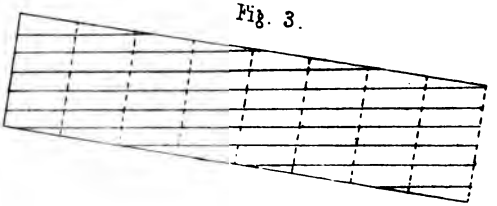

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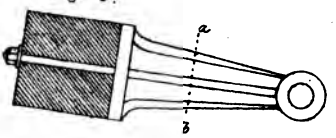

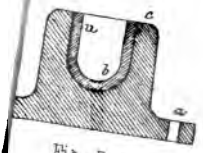

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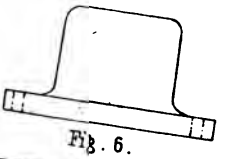

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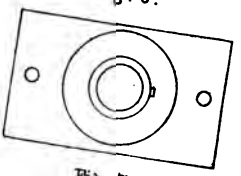

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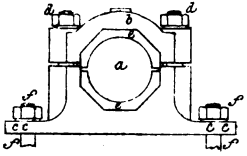
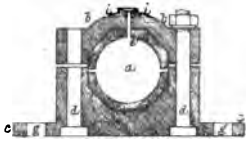


Fig. 1



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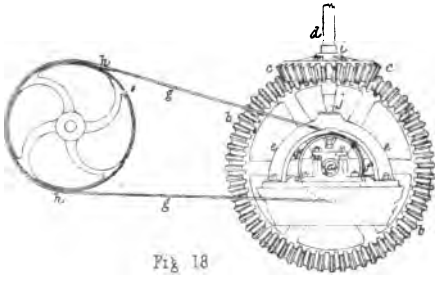
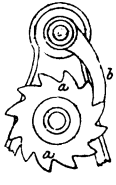


Fig 18



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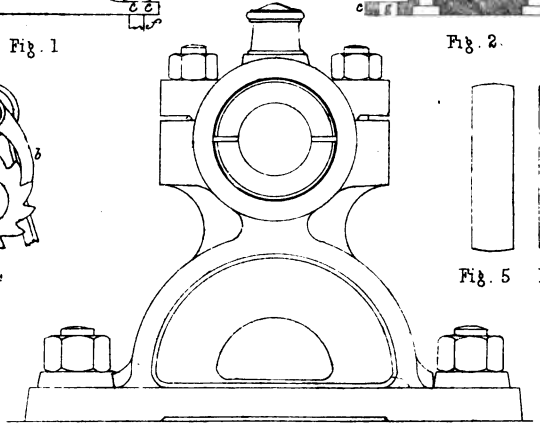

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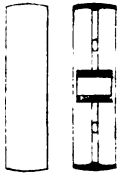
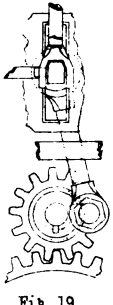


Fig. 5

Fig. 6



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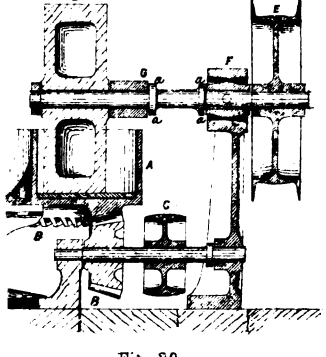

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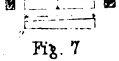

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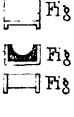


Fig. 8.

Fig. 9

Fig. 10

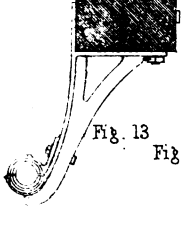


Fig. 13

Fig. 11.

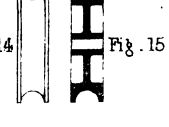
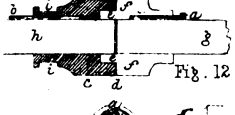


Fig 14

Fig. 15



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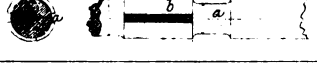


Fig. 16.

Fig. 17

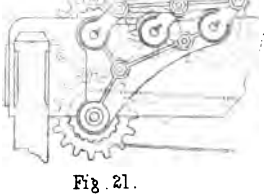
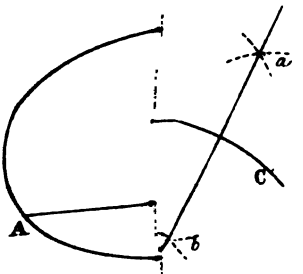
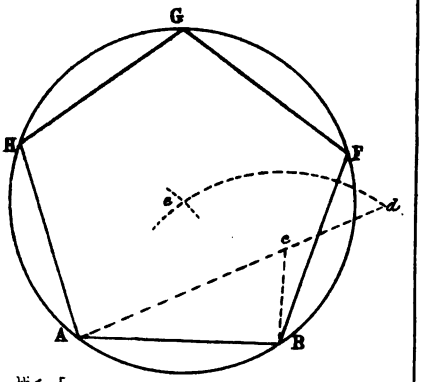


Fig. 21.

Fig. 22

Fig. 23





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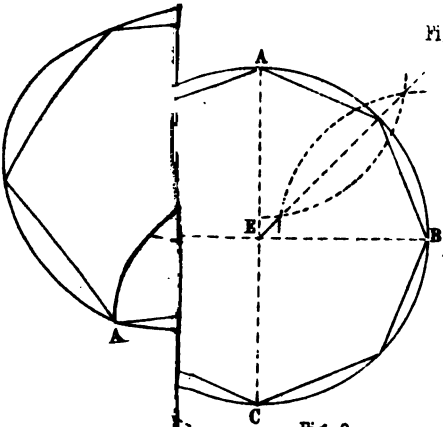

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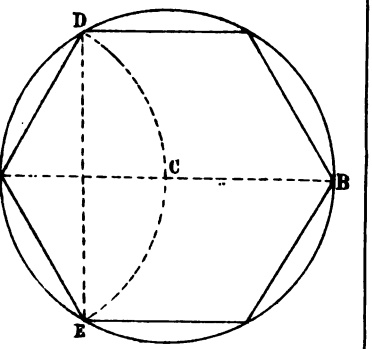

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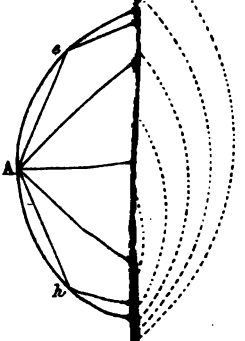

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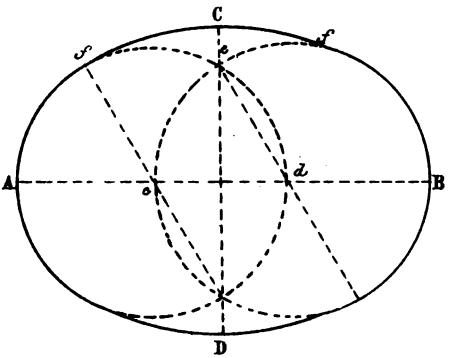
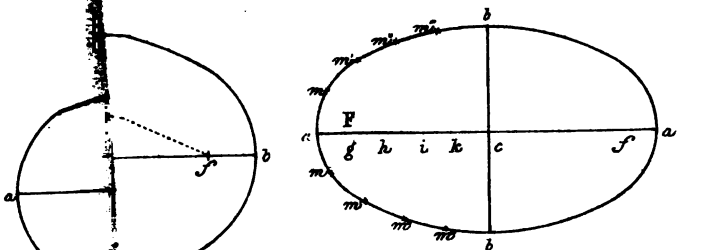


Fig. 13.

W.H.M^c Farlane, Lith^r Edin^r



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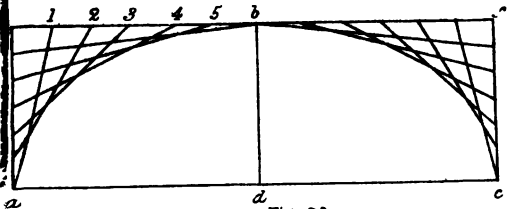

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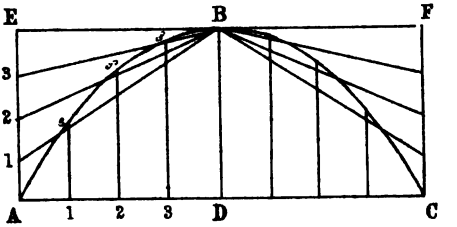

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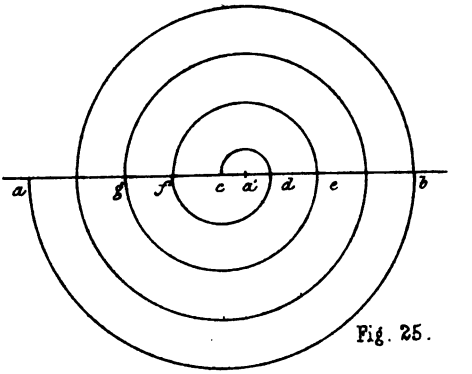

Fig. 25.

W.H.M.c Farlane, Lith.r Edin.r

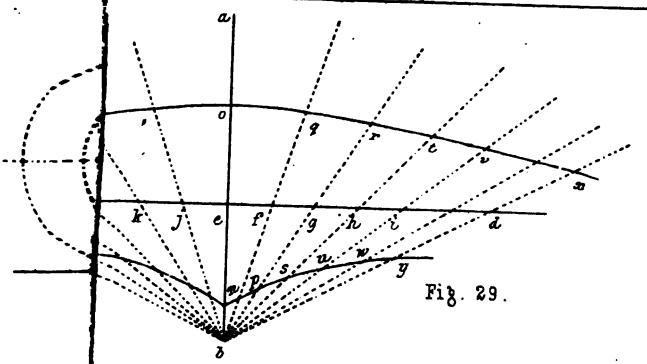

Fig. 29.

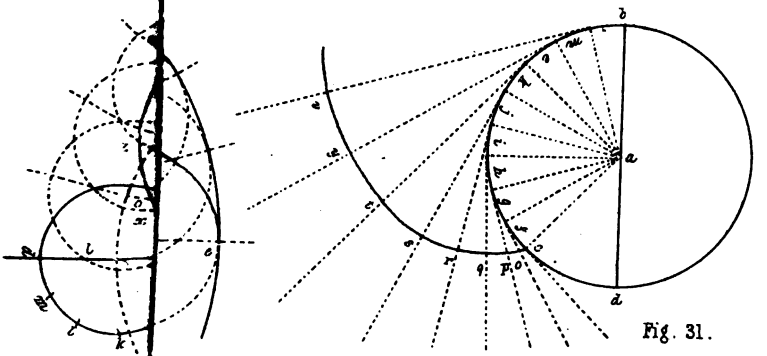

Fig. 31.

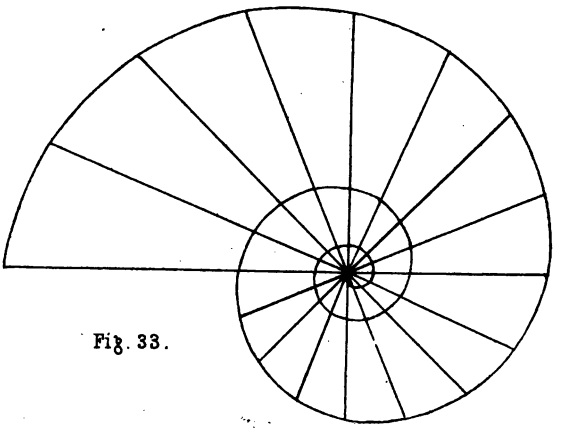

Fig. 33.

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